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INVESTIGATION OF A WEIR-DESIGN ALTERNATIVE FOR COASTAL FISHERIES BENEFITS

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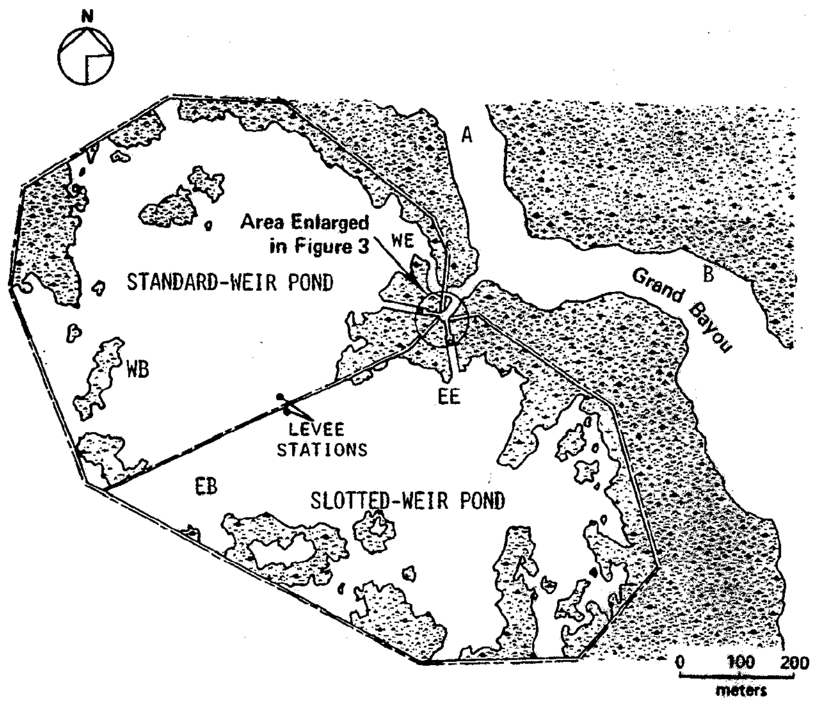

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ABSTRACT

Standard fixed-crest weirs have been demonstrated to reduce fish and crustacean emigrations from the marsh nursery area back toward the Gulf of Mexico. These weirs are continuing to be constructed for wildlife habitat enhancement. The effect of weirs on emergent vegetation is unclear although some research has suggested that emergent marsh vegetation in water-logged soils may experience reduced growth.

The objective of this study was to determine whether modification of a standard fixed-crest weir would result in greater export of fishery organisms from the area controlled by the weir. Total catch of emigrating organisms was taken from two nearly identical marsh ponds by traps with a mesh opening of 0.203 inch. Both ponds had a standard fixed-crest weir at the only entrance/exit, with one weir having a vertical slot from top to bottom. Data were collected from 15 February through 30 July 1986, which encompassed the majority of the brown shrimp (Penaeus aztecus) marsh nursery cycle. Salinity, water temperature, and water levels were measured in both ponds and in the nearby waters. Trawling was conducted in these experimental ponds and in a nearby control pond, which had no water-control structure.

Over 241% more brown shrimp (84% in biomass) emigrated from the pond with the slotted weir than from the pond with the standard weir. Both the standard and slotted weir were suspected of delaying immigration and emigration for brown shrimp. The slotted weir apparently yields median results between the control pond (early and abundant immigration, early emigration, low mean size, and high rate of cycling) and the standard weir (later and less abundant immigration, delayed emigration, increasing greater mean size, and low rate of cycling).

For all species combined, over 60% more organisms (62% in biomass) emigrated from the slotted-weir pond for the study period. For the time period studied, the salinities and water levels were generally similar. Water levels in the slotted-weir pond had slightly greater range and standard deviation, however the water level in the slotted weir pond did not drop nearly as low as the water levels outside the experimental ponds.

Compared to a standard fixed-crest weir, a slotted weir would provide enhanced fishery access and utilization. The slotted and standard weirs should be evaluated for their effect on emergent vegetation, water levels, salinities, and wildlife and fishery organisms other than brown shrimp.

INTRODUCTION

Standard fixed-crest weirs have been implicated in affecting the movements and abundance of many estuarine organisms (Herke 1968, 1971, 1979; Wengert 1972; Herke et al. 1984a, 1985, 1987a,b). Most of the economically-important species that spawn nearshore and migrate into the marsh nursery areas have been either less abundant in these semi-impounded areas (those affected by weirs) (Wengert 1972, Herke et al. 1987a) or the fisheries export from the nursery area was reduced (Herke et al. 1987b). Perry (1981) concluded that weirs did not prohibit brown shrimp (Penaeus aztecus) from entering the marsh because he found shrimp behind a weir; however, he had no control (non-weired) area for comparison. Thus, he was unable to determine whether brown shrimp movement and abundance was reduced by the weir. Several other studies documented shrimp behind weirs, but these have only been a measure of standing crop and did not considered the turnover rate (cycling in and out). The productivity of an area can not be based on standing crop alone, but must consider the cycling of organisms. Two areas may have equal standing crops, but one could have many times the productivity, if the turnover rate is greater.

The actual behavioral mechanisms by which water-control structures affect the movement of organisms are not known. One likely mechanism is the reduction in water exchange. Herke et al. (1984b) and Schultz (1985) demonstrated that most of the organisms move with the current. Bradshaw (1985) found significantly lower densities of postlarval and juvenile brown shrimp in a semi-impounded area as compared to an adjacent non-weired area. Thus, the reduction in water exchange may reduce the number of the young larval and juvenile immigrants. Another possible mechanism is the creation of an ethological barrier by weirs (Herke 1979). That is, the organisms could physically cross the weir but behavioral traits prevented their crossing. Another likely mechanism is the blocking by weirs of a specific portion of the water column at which certain organisms would prefer to migrate; e.g., Herke et al. (1984a) suggested that weirs may impede the movement of juvenile spotted seatrout (Cynoscion nebulosus) entering the marsh because they migrate at the middle and lower portions of the water column. King (1971), Herke et al. (1984b, 1987b), Rogers and Herke (1985a,b), and Schultz (1985) present data on the vertical migration levels of many organisms.

Weirs have been used for many purposes, in Louisiana they have been traditionally used to enhance the habitat for waterfowl and furbearers (Chabreck and Hoffpauir 1965; Chabreck 1968). Weirs maintain a minimum water level and sometimes reduce turbidity, thereby stimulating the growth of widgeongrass, Ruppia maritima, and other submerged aquatic vegetation, important food plants for waterfowl (Wicker et al. 1983). The effects of weirs on other types of vegetation have not been well studied. Weirs are installed to reduce marsh erosion, although we know of no documented evidence that they are effective for this purpose in brackish or saline marshes.

Mendelssohn and Seneca (1980) and Mendelssohn et al. (1980) have demonstrated that saltmarsh cordgrass, Spartina alterniflora, has lower levels of standing crop and growth when the drainage is impaired or the plants are in waterlogged soils. These authors attribute decreased growth to increased anaerobic metabolism and subsequent increases in waste products of anaerobic metabolism, e.g. sulfides. Perhaps the longer inundation period caused by the weirs may be detrimental to saltmeadow cordgrass, Spartina patens, as well. At this point, not nearly enough is known about the short or long term effects of weirs on the marsh and the emergent vegetation.

Perhaps better structures can be designed that will perform basically the same marsh management functions as those of fixed-crest weirs, while allowing greater fishery organism usage and movement. Such structures may greatly improve fishery resources, while maintaining or enhancing benefits to other wildlife (especially when considering the questionable effects of weirs on emergent vegetation).

The objectives of this study were to; 1) compare the catches of fishery organisms emigrating from two marsh ponds, one having a standard fixed-crest weir and the other having the same weir structure but modified to include a 4-inch vertical slot from top to the bottom of the channel, and 2) monitor water level, salinity, and water temperature in each pond. Although several structures were discussed as possible test designs, the vertically-slotted, fixed-crest weir was chosen due to the ease of design and construction, lower cost, and the allowance of movement of organisms throughout the entire water column. When applied in marsh management, this slotted design would improve fisheries access with minimal active structural management and would allow easy closing of the slot, if necessary.

METHODS AND PROCEDURES

Trap

This study utilized two marsh ponds that were located in the East Cove portion of the Sabine National Wildlife Refuge in the Grand Bayou watershed, Cameron Parish, Louisiana (Fig. 1). These ponds were also used by Herke et al. (1987b). The ponds were constructed in October 1982 by surrounding a portion of a single natural marsh pond with a ring levee and installing a cross levee, such that the natural pond was divided into two 87-acre experimental ponds (Fig. 2). Each pond enclosed about 65 acres of water and 22 acres of predominantly *Spartina patens* marsh. These two ponds will be collectively referred to as the experimental ponds. The control pond (Fig. 2) had no water-control structure and was used only for trawl sampling (to be presented later).

A single wooden chute, constructed of plywood and pilings, installed in each pond levee, was the only entrance/exit channel for tidal exchange and aquatic organisms (Fig. 3). These chutes were 6 feet wide, 8 feet deep and 40 feet long. The bottom of each chute was about 4 feet below average water level. Identical trap systems were installed in each chute (Fig. 3). Each trap was 6 feet tall, 6 feet long, and 2 feet wide, and was constructed of welded aluminum alloy covered with monel, market-grade, wire cloth, having 0.047-inch diameter wire and 0.203-inch openings. The end of the trap facing the pond had a V-shaped mouth with a 2-inch vertical slit to funnel emigrating organisms into the trap. A similar mouth with a 3/4-inch vertical slit was placed in the middle of the trap to allow smaller organisms to retreat to the rear of the trap (Fig. 3). This was done to segregate the larger blue crabs (*Callinectes sapidus*) from the smaller organisms, which hampered the crabs from mutilating or consuming the smaller organisms. Deflecting screens, made of the same mesh as that of the traps, were installed to guide immigrating organisms toward a 3-inch (7.62 cm) slot at the pondward edge of the chute and deflecting screens (Fig. 3). This 3-inch slot had a deflector placed on the pondward side to guide outgoing organisms past this slot. The deflecting screens also guided emigrating organisms into the trap. Thus, immigrants were easily guided into the ponds but all emigrants too large to pass through the mesh were trapped.

A complete history of the various water-control structures used at

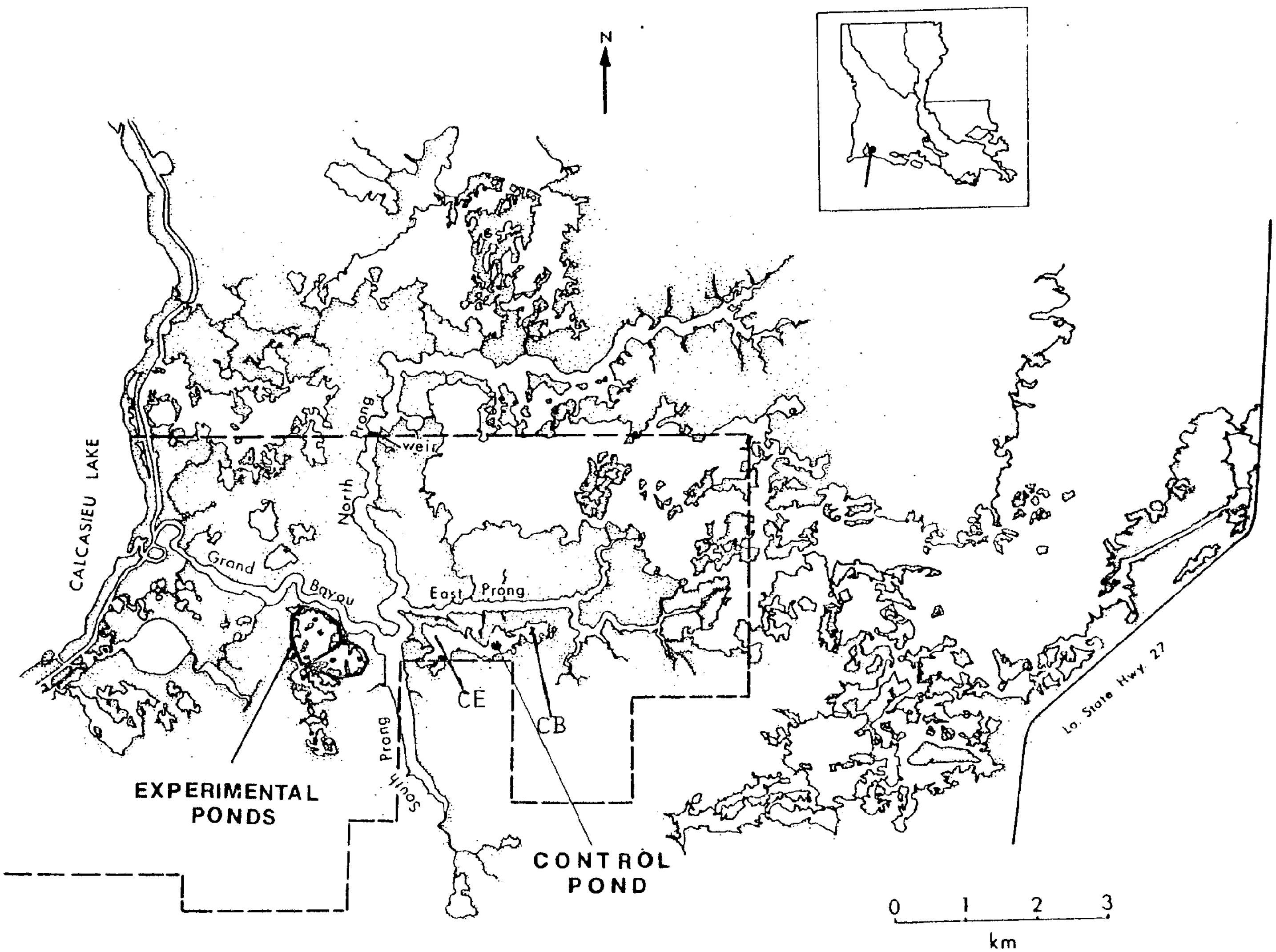


Figure 1. Grand Bayou study area showing the paired ponds and the trawling stations in the control pond.

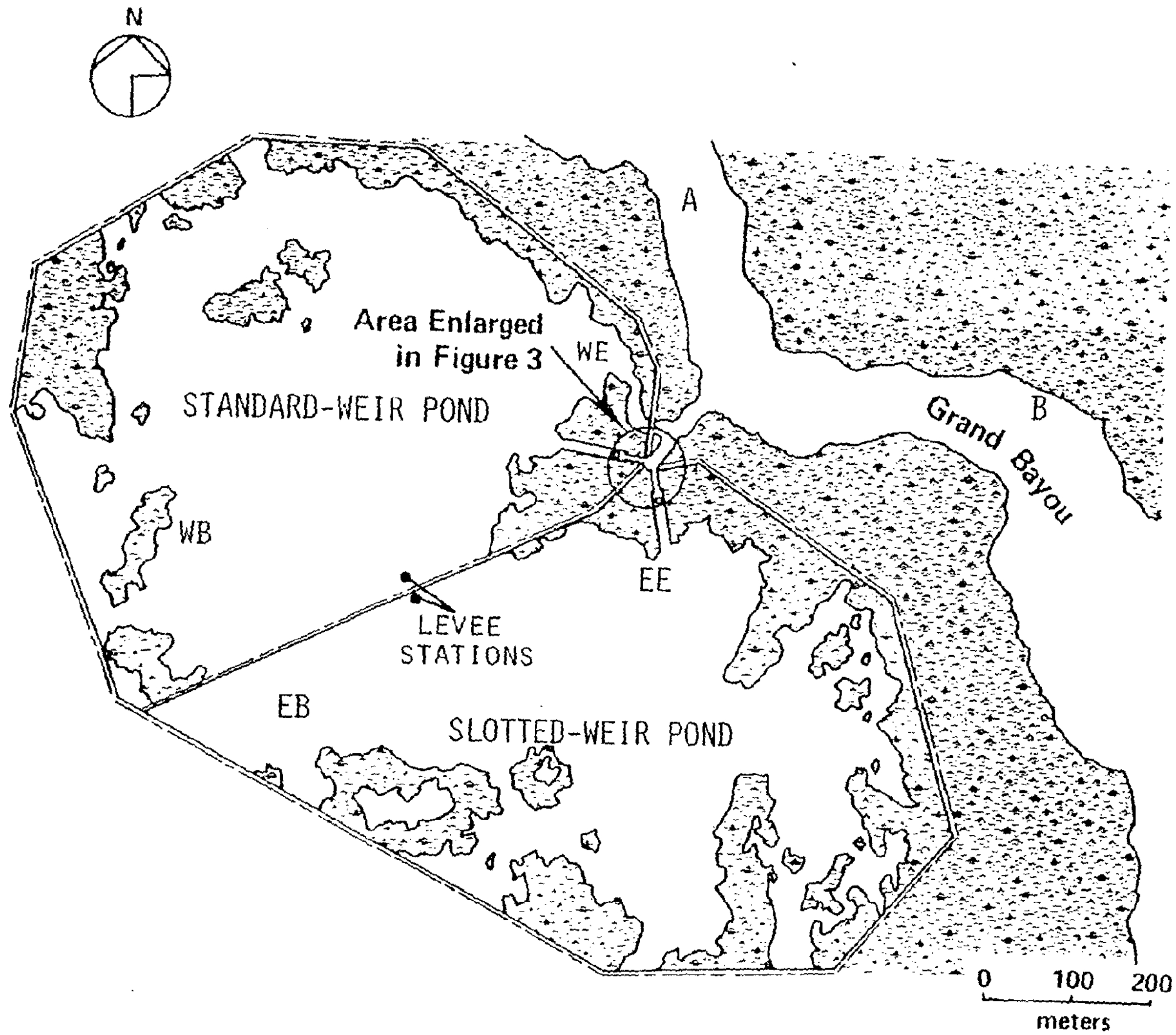


Figure 2. Diagram of the paired ponds showing the trawling stations (WE, WB, EE, and EB), the Grand Bayou salinity stations (A and B), and the levee salinity stations in each pond.

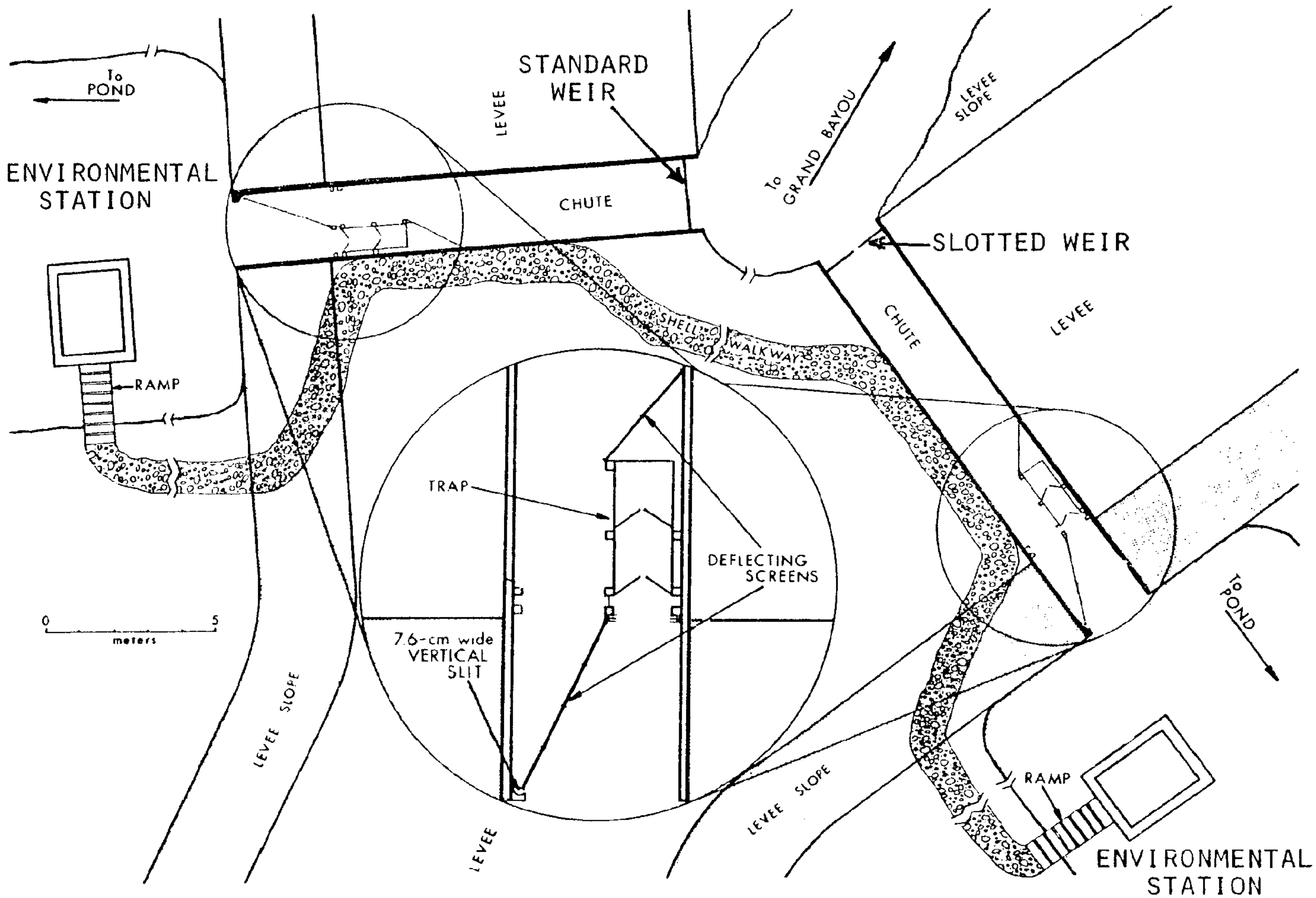


Figure 3. Diagram of the experimental-ponds trapping system showing the location of the standard and slotted weirs and the environmental stations.

these experimental ponds by Herke et al. (1987b) and during this study is as follows:

Dates	Pond East	Pond West
12 Feb 1983 - 13 Feb 1984	weir	no weir
13 Feb 1984 - 20 Apr 1985	no weir	weir
20 Apr 1985 - 24 Aug 1985	no weir	no weir
24 Aug 1985 - 22 Nov 1985	no weir	weir
22 Nov 1985 - 20 Dec 1985	no weir	no weir
20 Dec 1985 - present	slotted-weir	weir

On 22 November 1985 the weir on the west pond was removed, to allow both ponds to be open (no structure), with the idea to let the ponds equilibrate in terms of salinity, water level, and fishery organisms. On 20 December 1985, a standard, fixed-crest weir (referred to as the standard weir) was installed on the Grand Bayou side of the trap in the west pond chute (Figs. 2 and 3). The crest of this weir was set 6 inches below average marsh soil level and had a length of 65 inches. On the same date, a standard fixed-crest weir with a 4-inch vertical slot (referred to as the slotted weir) was placed in the chute for the east pond. This vertical slot stopped 3 inches from the bottom, because a 3- X 6-inch timber was used for support across the bottom (Fig. 4). The 3.5- X 3.5-inch vertical timbers and the interior stoplog guides reduced the crest of the slotted weir to 61 inches (Fig. 4). Thus the slot width comprised 6.5% of the weir crest length, i.e., 1 inch of slot per 15.2 inches of weir crest length. The weir crest length was longer than normally used in practice (e.g. 1 foot of weir crest per 70 acres of semi-impounded marsh) because 6-foot wide chutes were necessary for installation of the traps and deflecting screens.

Fish, shrimp, and crabs migrating into the ponds, after negotiating either weir, could either pass through the mesh of the deflecting screens and trap, or through the 3-inch wide vertical slot at the pondward end of the deflecting screens (Fig. 3). Incoming organisms too large for this opening were excluded; however, most were small enough to gain access. All organisms too large to pass through the mesh were captured when emigrating from each pond. The traps fished **continuously**

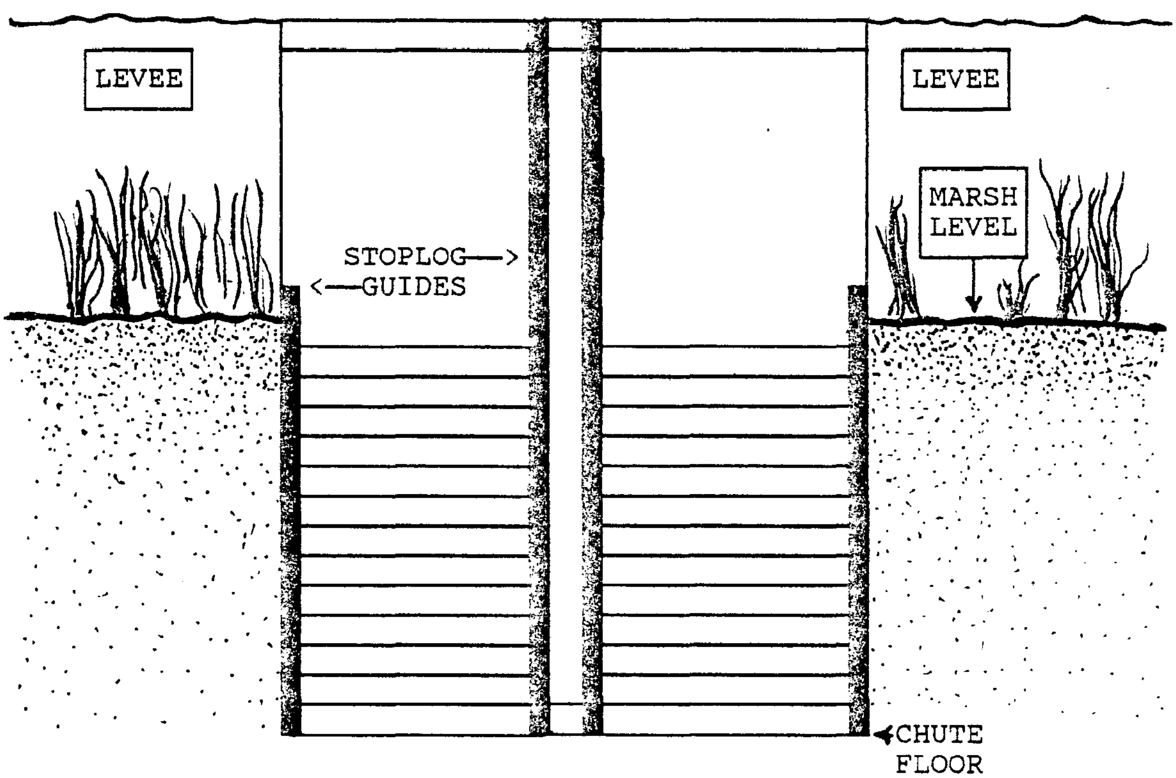


Figure 4. Sketch of the slotted weir as viewed from the end of the chute. The 61-inch weir crest was set at 6 inches below average marsh soil level. The 4-inch slot went from the weir crest to within 3 inches from the floor of the chute. The bottom stoplog was one continuous timber to provide support for the interior stoplog guides.

and were emptied between 0800 and 1000 hours **daily** from 15 February 1986 through 30 July 1986 (including holidays and weekends). A drop screen, of identical mesh as the traps, was lowered in front of each trap to prevent passage of organisms while the trap was being emptied. The entire catch was placed in ice until processing.

The catch for each trap was sorted by species. Several species were further sorted into categories as follows:

Blue crab (Callinectes sapidus)
- small blue crab (less than 25 mm; i.e., not easily sexed)
- immature female crab
- mature female crab
- male crab

Ladyfish (Elops saurus)
- leptocephalus
- juvenile

Speckled worm eel (Myrophis punctatus)
- leptocephalus
- juvenile/adult

The total number of individuals and total weight (in grams) taken each day were determined for each species or other category, as described above; these data were then coded onto a personal computer in the field lab. Excessively large catches of a species were subsampled by a method described by Herke (1978). When the entire sample was too large to be sorted, subsampling was done at the total catch level (i.e., before sorting to species). The subsample weight and the remainder weight for both techniques were used to estimate the number of each species in the entire catch.

The pond trap data were total catches of all organisms retained by the trap and deflecting-screen mesh while emigrating from each pond, thus the total catches were a census of the popualtions. Therefore, to test the hypothesis "catches of emigrating organisms from the two ponds were equal" required no statistics, because the catches were the statistical (and biological) populations, not samples of the populations. [Most fishery research projects sample once a week or so (at best), and must use statistics to account for the lack of data between sample dates, but this study took complete data from all dates.]

Thus, we did not have to estimate data or derive confidence limits because we took the entire populations from each experimental pond.

Daily salinity and water temperature readings were taken at the environmental and levee stations for each pond (Fig. 2 and 3). Daily readings at the levee stations and stations A and B in Grand Bayou were taken with a Beckman RS-5-3 meter, and at the environmental stations with a Hydrolab 8000. (Grand Bayou salinity data collection began on 4 April 1986.) The Hydrolabs also recorded salinity and water temperature once per hour from 17 January 1986 through 30 July 1986. Daily water level readings were taken at the chutes in both ponds and in Grand Bayou. (Grand Bayou water level data collection began on 4 March 1986.) A Leupold-Stevens tide gauge, located at the environmental stations, recorded hourly water level readings in each pond.

Trawling

Trawling was conducted every two weeks from 6 March 1986 through 30 July 1986. Two trawling stations were located in each experimental pond and in the control pond (Figs. 1 and 2). The control pond was a natural area not affected by any water-control structure. The stations were located in each of the three ponds such that two locations were sampled, one near the entrance (e.g., CE - Control Entrance) and another near the back (e.g., WB - West Back) of each pond. Each station was sampled with a 16-foot and a 6-foot trawl. The 16-foot trawl had 5/8-inch bar mesh in the body and 1/4-inch bar mesh in the cod end, and was towed for 5 minutes (approximate distance of 1/4 mile) with 75-foot ropes from an airboat. The 6-foot trawl had 5/16-inch bar mesh in the body and 3/16-inch bar mesh in the cod end, and was pushed in front of the airboat for 5 minutes (approximate distance of 1/4 mile) along the shoreline as described by Rogers (1985). Trawl samples were processed in the same manner as the trap samples. Salinity and water temperature were measured before each trawl haul with the Beckman instrument.

Data Analysis

This study was designed to encompass, as much as practical, the seasonal presence of brown shrimp in the marsh. The marsh nursery cycles of the many other important species were not entirely covered by the study. Consequently discussions for these species are presented in much less detail than for brown shrimp, which was the target species of this study.

To compare the total catch between the two ponds, percent change in catch and biomass of organisms emigrating from the slotted-weir pond as compared to the same from the standard-weir pond was calculated as follows:

$$\text{Percent Change} = ((SLW/STW)-1) \times 100$$

where

SLW = total catch or biomass taken in the slotted-weir pond

STW = total catch or biomass taken in the standard-weir pond

This formula essentially sets the catch in the standard-weir pond to 100%. For example, a percent change of 50 would indicate an increase in catch of 50% from the slotted-weir pond compared to the standard-weir pond, referred to as a 50 percent <u>increase</u>. A percent change of -50 would indicate a 50% decrease in catch from the slotted-weir pond compared to the standard-weir pond, referred to as a 50 percent <u>decrease</u>.

For most graphic and tabular presentation, the trawl data were combined (trawls and stations) for each pond by date. Brown shrimp trawl catch was analyzed by analysis of variance with a split-plot (split on gear) arrangement of treatments (PROC GLM, SAS 1985). Pond, location (entrance or back), and date were the main effects and date was further examined by its linear (D), quadratic (D*D), and cubic (D*D*D) components.

RESULTS AND DISCUSSION

Brown Shrimp

Since the fishery data were collected for only 5.5 months (15 February 1986 - 30 July 1986), total comparison of the function of the two structures for all species is impossible, because some of the species had not completed their yearly cycling in and out of the marsh nursery. The structures were installed on 20 December 1985 (2 months before sampling began), thus the fishery data collected should reflect what happened during the study period, there being little influence of the initial installation of the structures. Of the most recreationally and commercially important species, some gulf menhaden and Atlantic croaker individuals may have entered the pond before the structures were installed (Rogers and Herke 1985a). Brown shrimp would have begun the marsh part of their life cycle after the structures were installed, and would have basically finished the majority of the marsh part of their life cycle before the study ended (Rogers and Herke 1985a).

The trap data revealed that brown shrimp catches from the slotted weir pond were 241% greater in numbers and 84% greater in biomass than from the standard-weir pond (Table 1). This increased catch from the slotted-weir pond was consistent throughout the study (Fig. 5). Brown shrimp emigration began about 3 weeks earlier in the slotted-weir pond (Fig. 5) and appears to be related to the lunar or tidal phases as noted by (Herke et al. 1987b). The mean weight of brown shrimp at emigration was consistently greater in the standard-weir pond over time (Fig. 5) and when all shrimp weights were averaged (Table 2).

Brown shrimp trawling data contributed additional information. Analysis of variance (PROC GLM, SAS 1985) using a split-plot (split on gear) arrangement of treatments was conducted (Appendix Table 1). The analysis indicated a highly significant difference due to the pond main effect ($P < 0.01$) but, significant interactions with date [particularly for the quadratic ($P < 0.0001$) and cubic ($P < 0.0248$) components] precludes a simple interpretation about the pond catch differences. Essentially, the catch in the three ponds varied differently in relation to one another over time. Even though the control pond was more

Table 1. Trap catch, biomass, and percent change for both experimental ponds.

	NUMBER			BIOMASS (G)		
SPECIES	STANDARD WEIR	SLOTTED WEIR	PERCENT CHANGE[1]	STANDARD WEIR	SLOTTED WEIR	PERCENT CHANGE[1]
grass shrimp	270,907	388,977	44	133,995	141,183	5
gulf menhaden	219,279	279,171	27	297,798	207,805	-30
brown shrimp	28,681	97,694	241	244,536	449,176	84
Atlantic croaker	22,193	34,176	54	236,704	170,484	-28
white mullet	15,902	21,773	37	167,052	109,461	-34
inland silverside	13,451	36,766	173	15,144	30,441	101
immature female crab	9,018	28,364	215	318,847	504,321	58
male blue crab	8,689	24,874	186	672,912	1,152,386	71
gulf killifish	6,350	11,988	89	28,880	51,509	78
diamond killifish	4,327	3,890	-10	2,032	1,600	-21
spot	4,045	15,805	291	32,784	49,471	51
striped mullet	3,560	12,921	263	38,391	666,024	1635
sheepshead minnow	3,540	7,464	111	4,917	10,501	114
sailfin molly	3,165	1,495	-53	3,750	1,868	-50
naked goby	1,859	2,071	11	1,187	1,388	17
bay anchovy	1,614	1,970	22	2,395	2,202	-8
darter goby	1,116	2,223	99	1,075	1,899	77
pinfish	529	6,115	1056	8,717	63,663	630
blue crab (less than 25 mm)	472	6,576	1293	274	2,594	846
mature female crab	421	349	-17	74,419	60,483	-19
white shrimp	368	2,222	504	552	8,886	1511
rainwater killifish	274	1,013	270	196	685	250
speckled worm eel	115	72	-37	1,267	821	-35
blackcheek tonguefish	112	300	168	1,417	2,660	88
bayou killifish	108	83	-23	130	106	-18
bay whiff	76	532	600	911	4,902	438
mosquitofish	70	38	-46	34	22	-37
clown goby	58	41	-29	63	35	-45
mud crab	43	25	-42	7	6	-9
ladyfish	38	49	29	432	224	-48
sharptail goby	30	390	1200	515	5,666	1000
sand seatrout	18	37	106	484	759	57
southern flounder	13	115	785	5,636	14,976	166
black drum	5	5	0	23	26	17
rough silverside	5	1	-80	9	1	-85
redear sunfish	4	6	50	36	44	25
longnose killifish	3	2	-33	46	7	-86
sheepshead	3	4	33	57	14	-74
red drum	2	18	800	225	3,953	1660
least puffer	2	49	2350	2	82	3627

Table 1. continued.

SPECIES	NUMBER STANDARD WEIR	NUMBER SLOTTED WEIR	NUMBER PERCENT CHANGE	BIOMASS (G) STANDARD WEIR	BIOMASS (G) SLOTTED WEIR	BIOMASS (G) PERCENT CHANGE
violet goby	2	1	-50	255	76	-70
Atlantic cutlassfish	2	1	-50	228	61	-73
green goby	2	9	350	1	3	93
threadfin shad	1	1	0	4	2	-39
fiddler crab	1			2		
spotted seatrout		2			21	
silver perch		3			15	
Atlantic midshipman		1			3	
crevalle jack		1			2	
hardhead catfish		7			1,389	
leatherjacket		2			1	
inshore lizard fish		1			55	
bluefish		3			2	
gizzard shad		5			46	
snapping shrimp		1			2	
Atlantic spadefish		1			17	
bluegill		1			5	
pipefish		21			26	
squid		3			79	
worm eel leptocephalus		2			40	
fat sleeper		1			5	
	=======	=======	====	=========	=========	====
	620,473	989,731	60	2,298,341	3,724,187	62

[1] Percent change is calculated by ((slotted-weir catch / standard-weir catch) - 1) X 100.

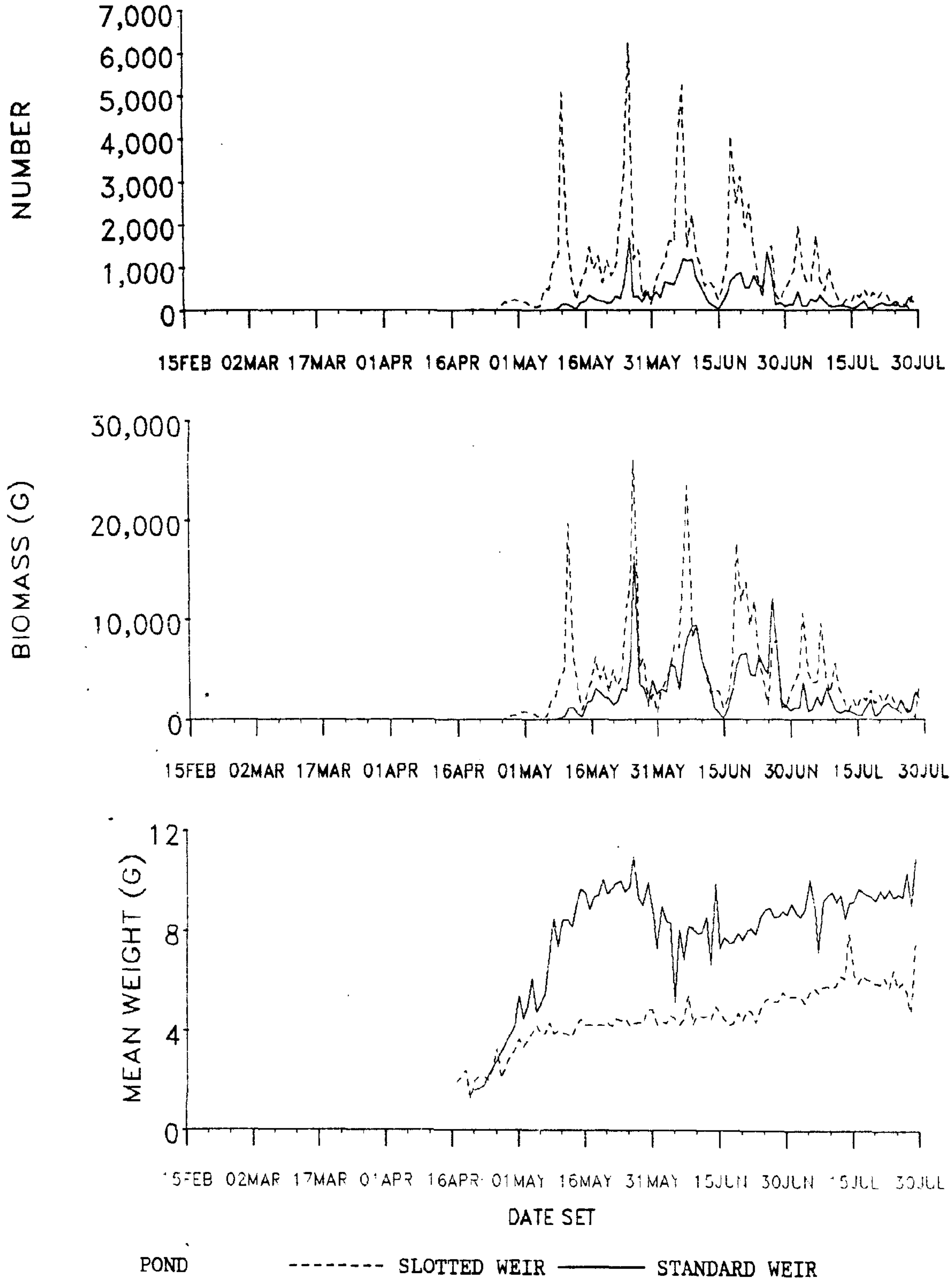


Figure 5. Number, biomass, and mean weight of brown shrimp taken by the traps in each pond.

Table 2 . Mean weight in grams, and percent change, of an individual organism taken by the traps. Values are computed for those species that had a total catch of 50 or greater in each experimental pond.

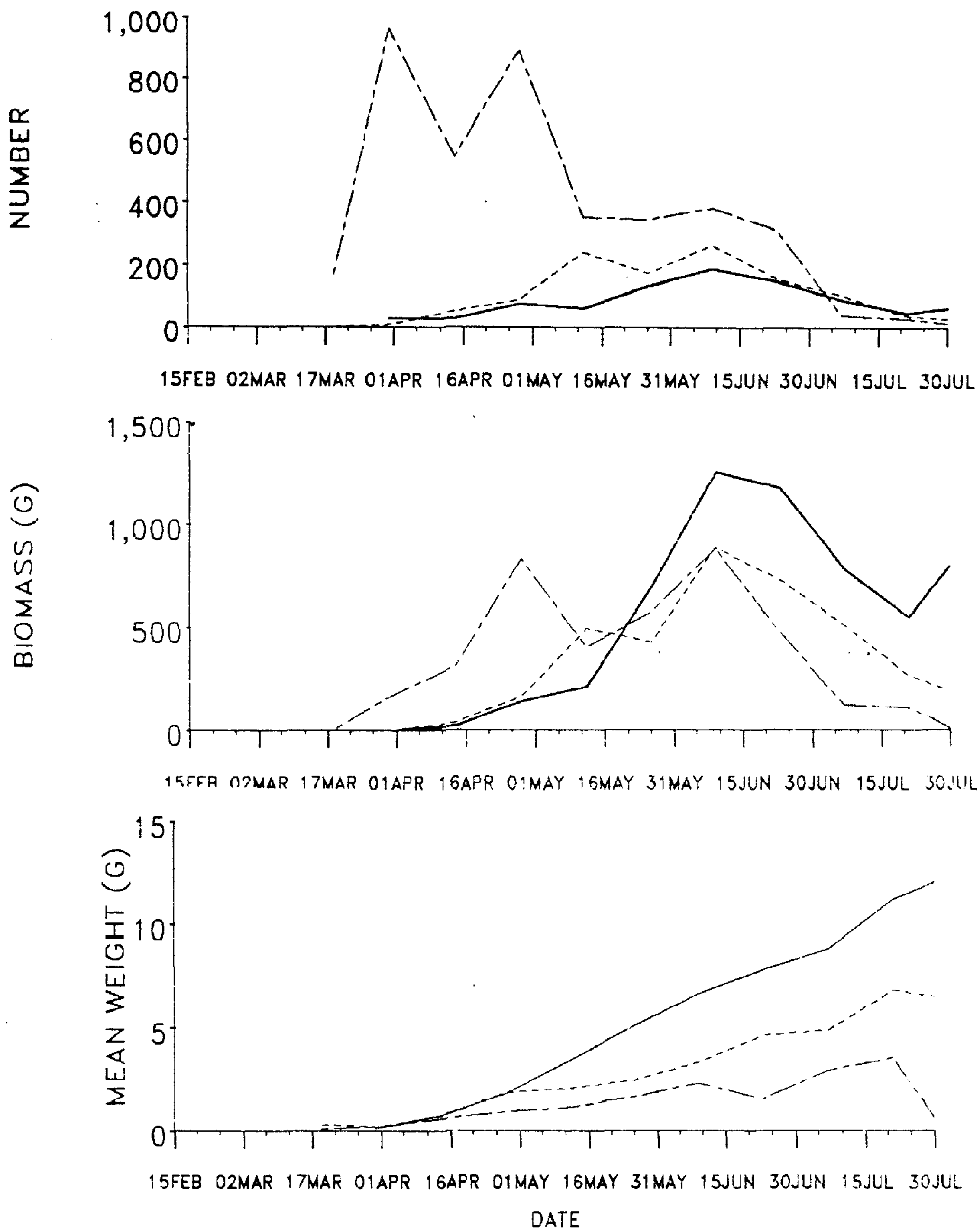
SPECIES	STANDARD WEIR	SLOTTED WEIR	PERCENT CHANGE[1]
mature female crab	176.8	173.3	-2
southern flounder		130.2	
striped mullet	10.8	51.5	378
male blue crab	77.4	46.3	-40
immature female crab	35.4	17.8	-50
sharptail goby		14.5	
speckled worm eel	11.0	11.4	3
pinfish	16.5	10.4	-37
bay whiff	12.0	9.2	-23
blackcheek tonguefish	12.7	8.9	-30
Atlantic croaker	10.7	5.0	-53
white mullet	10.5	5.0	-52
brown shrimp	8.5	4.6	-46
gulf killifish	4.5	4.3	-6
white shrimp	1.5	4.0	167
spot	8.1	3.1	-61
sheepshead minnow	1.4	1.4	1
bayou killifish	1.2	1.3	6
sailfin molly	1.2	1.2	5
bay anchovy	1.5	1.1	-25
darter goby	1.0	0.9	-11
inland silverside	1.1	0.8	-26
gulf menhaden	1.4	0.7	-45
rainwater killifish	0.7	0.7	-5
naked goby	0.6	0.7	5
diamond killifish	0.5	0.4	-12
blue crab (less than 25 mm)	0.6	0.4	-32
grass shrimp	0.5	0.4	-27
mosquitofish	0.5		
clown goby	1.1		

1 Values in this column are rounded from calculations carried to three decimal places.

distant from the Gulf, the brown shrimp appeared earlier and in greater abundance in the control pond than in the two experimental ponds (Fig. 6). The control pond was not affected by water-control structures, suggesting that the two experimental structures delayed and reduced recruitment and subsequent standing crops. Even though trap catch from the slotted-weir pond was 2.4 times that from the standard-weir pond, the standing stock trawl estimates for the two experimental ponds were similar in numbers (Fig. 6). This clearly illustrates what was pointed out in the Introduction: two areas may have equal standing stock, yet one may have much higher productivity if its turnover rate is faster.

The standing stock biomass was greatest in the standard-weir pond in the latter part of the study (Fig. 6). This was mainly due to the larger shrimp in the standard-weir pond, and was probably a result of delayed emigration from that pond, as noted by Herke et al. (1987b). The biomass peaked earliest in the control pond, again indicating that both structures delayed immigration.

The mean weight of brown shrimp from trawl catches was highest and had the greatest increase with time in the standard-weir pond, was intermediate for the slotted-weir pond, mean weight was the lowest and had the least increase with time in the control pond (Fig. 6). Trap catch in the slotted-weir pond was 241% higher than in the standard-weir pond (Table 1); standing crops in the two ponds were similar (Fig. 6) and total trawl catch in the slotted-weir pond was only 32% greater than in the standard-weir pond (Table 3). The only logical conclusion is that brown shrimp were cycling in and out of the slotted-weir pond in less time than the standard-weir pond. Therefore, the greater mean weight and greater increase with time in the standard-weir pond must have been due primarily to a greater delay in emigration from that pond. This resulted in older, and thus larger, shrimp being caught. This conclusion agrees well with a brown shrimp mark and recapture study conducted by Herke et al. (1987b), who reported that brown shrimp were delayed by two weeks on the average from leaving a pond with a weir as compared to a pond with no water-control structure. The measures of standing crop in numbers (Fig. 6) were considerably higher from the control pond, whereas the mean shrimp weight taken in the control pond



POND ———— CONTROL ----- SLOTTED WEIR ——— STANDARD WEIR

Figure 6. Number, biomass, and mean weight of brown shrimp taken by the trawls in each pond.

Table 3. Number and biomass taken by both trawls in the three ponds.

SPECIES	NUMBER STANDARD WEIR	NUMBER SLOTTED WEIR	NUMBER CONTROL	BIOMASS STANDARD WEIR	BIOMASS SLOTTED WEIR	BIOMASS CONTROL
grass shrimp	29,583	53,898	18,247	4,083	8,788	3,727
gulf menhaden	6,444	10,389	51,047	3,560	6,428	23,494
inland silverside	5,753	6,489	4,509	4,355	4,090	2,860
spot	1,005	2,590	8,026	4,465	6,999	13,078
white shrimp	440	1,341	2,596	1,192	2,153	1,437
Atlantic croaker	919	1,293	1,190	5,229	3,978	3,311
brown shrimp	879	1,162	4,050	5,615	3,688	3,881
pinfish	477	665	249	4,498	5,277	2,085
bay anchovy	837	641	5,821	750	553	1,931
rainwater killifish	160	521	736	81	235	349
striped mullet	548	312	201	813	2,058	2,163
immature female crab	136	197	35	1,959	1,962	667
male blue crab	146	181	36	5,090	3,235	1,250
naked goby	183	157	38	107	55	20
gulf killifish	20	45	14	62	145	59
sheepshead minnow	31	42	26	25	41	36
diamond killifish	46	27	1	18	13	1
clown goby	20	25	1	21	24	1
darter goby	16	22	5	13	7	3
blue crab (lesss than 25 mm)	23	20	32	9	10	9
ladyfish	9	13	2	28	6	92
sailfin molly	77	12	16	45	13	11
white mullet	22	7	21	84	81	200
southern flounder		6	20		292	119
mud crab		5	23		1	11
mosquitofish	6	3	7	3	1	1
blackcheek tonguefish		3	1		33	11
least puffer		2	5		8	10
spotted seatrout	1	1	2	43	21	3
bay whiff		1	1		1	1
pipefish	16	1	9	18	1	8
ladyfish leptocephalus	4	1	69	0	0	7
sand seatrout			17			100
red drum			2			81
silver perch			2			19
black drum			2			532
crevalle jack			11			44
hardhead catfish			2			31
leatherjacket			3			3
inshore lizard fish			3			186
threadfin shad			5			20
gizzard shad			1			18
pigfish			1			1
scaled sardine			1			1
diamondback terrapin	1		1	45		471
chain pipefish			2			9
redear sunfish	2		10	20		88
green goby			1			1
sharptail goby	1			1		
rough silverside			28			62
TOTAL	47,805	80,072	97,128	42,232	50,199	62,504

(Fig. 6) was less than from either experimental pond. Therefore, brown shrimp must have cycled in and out of the control pond in the least time, while being retained longer by the slotted weir, and longest by the standard weir. This would explain the apparent discrepancy between the higher standing biomass in the standard-weir pond, but the lowest emigration, and subsequent contribution to the fishery, from that pond.

It is difficult to determine, from this study and others in the literature, which of these three regimes would be the best for maximization of brown shrimp production. We hypothesize that a higher abundance of smaller shrimp would be better for the resource than a considerably lower abundance of larger shrimp for several reasons. First, the greater numbers would allow brown shrimp to more fully utilize the environmental conditions that they may encounter following the marsh part of their life cycle. For example, if only a few large shrimp survive to return to the bays and offshore, and conditions are unfavorable, the total number (and biomass) surviving would be lower. Second, if more small shrimp leave the marsh, they have the potential to grow in size and produce several times the total biomass of the fewer larger ones. Third, the total biomass of numerous smaller shrimp leaving the slotted-weir pond was greater than the total biomass of larger but fewer shrimp leaving the adjacent standard-weir pond as seen in Table 1. Thus, there was relatively high survival <u>and</u> high biomass produced by the slotted-weir pond to continue growth and possibly provide a greater harvest.

Brown Shrimp Conclusions

1. The slotted weir allowed more individuals (241% more) and biomass (84% more) of brown shrimp to emigrate back towards the Gulf than did the standard weir.
2. Brown shrimp emigrated from the standard-weir pond later, and at a larger size, than from the slotted-weir pond.
3. Recruitment into the nursery and emigration were delayed and reduced by both structures, but more so by the standard weir.

4. Both structures reduced the cycling of brown shrimp in and out of the marsh nursery with the standard weir reducing it more.
5. Use of a slotted weir should result in more brown shrimp production than would use of a standard weir.

Species Composition

The interpretation for this section will only consider the time frame of this study (15 February 1986 through 30 July 1986). Except for brown shrimp, this study did not cover the entire marsh portion of the life cycle of most of the species.

To provide an indication of relative abundance and biomass of the species to each other, catch and biomass for all trawling and trapping combined are listed in Appendix Table 2, which also lists the common and scientific names for all organisms taken in the study. Appendix Figs. 1 - 29 contain the daily trap and periodic trawl catch, biomass, and mean weight for gulf menhaden, Atlantic croaker, spot, southern flounder, striped mullet, white mullet, grass shrimp, inland silverside, gulf killifish, sheepshead minnow, bay anchovy, blue crab (less than 25 mm), immature female blue crab, male blue crab, and mature female blue crab.

There was an overall increase of 60% in numbers of all species combined trapped while emigrating from the slotted-weir pond as compared to the standard-weir pond (Table 1). Of the species taken in enough abundance to make conclusions, the small blue crabs had the greatest increase in abundance (1293%), with pinfish having the second greatest increase (1056%). Brown shrimp, immature female blue crab, spot, striped mullet, and white shrimp each had increases of over 200%. Mature female blue crab was the only category of economically important species that decreased in abundance in the slotted-weir pond catch relative to the standard-weir pond.

There was an overall increase in biomass emigration (62%) from the slotted-weir pond (Table 1). The percent changes in biomass between the two ponds was much less, than it was by numbers, for most of the economically important species. Striped mullet, white shrimp, and small blue crabs had the greatest percent increase in biomass in the slotted-weir pond.

For trapping data, almost all estuarine-dependent organisms were larger in the standard-weir pond (Table 2, Appendix Figs 1 - 29), with the exception of white shrimp and striped mullet. However, not enough of the annual nursery cycle was studied to make any firm conclusions for white shrimp. Emigrating striped mullet were nearly 5 times larger in the slotted-weir pond trap catch than in the standard-weir pond trap catch.

The species trapped and the order of their abundances were similar in the two experimental ponds (Table 1). The order of abundance of the top eight categories were the same, with minor exceptions. Some 57 species emigrated from the slotted-weir pond whereas 42 emigrated from the standard-weir pond. A single fiddler crab was the only species taken in the catch from the standard-weir pond that did not occur in the slotted-weir pond. Although not always consistent, the slotted-weir trap generally caught more species on a daily basis (Fig. 7). The slotted-weir pond catch had many more organisms early in the study, but catches were about the same in the later half (Fig. 7). Except on a few occasions, the catch biomass was greater in the slotted-weir pond on a daily basis (Fig. 7).

Appendix Table 3 lists the catch and biomass for individual trawling stations. Trawling data did not show the differences between the experimental ponds as well as the trapping data. The number of species, total catch, and biomass were not distinctly different between ponds over time (Fig. 8). However, total catches over the study period from all three ponds did indicate that the slotted-weir and control pond had 67% to 103% greater standing crop in terms of numbers, and a 19% to 48% greater standing crop in terms of biomass than the standard-weir pond, respectively (Table 3).

These data again demonstrate that standing crop is not an indicator of productivity (as measured by the export from the ponds back towards the Gulf). Standing crop over time was not very different in the two experimental ponds (Fig. 8), nor was overall trawl catch by biomass (Table 3), but export was much greater from the slotted-weir

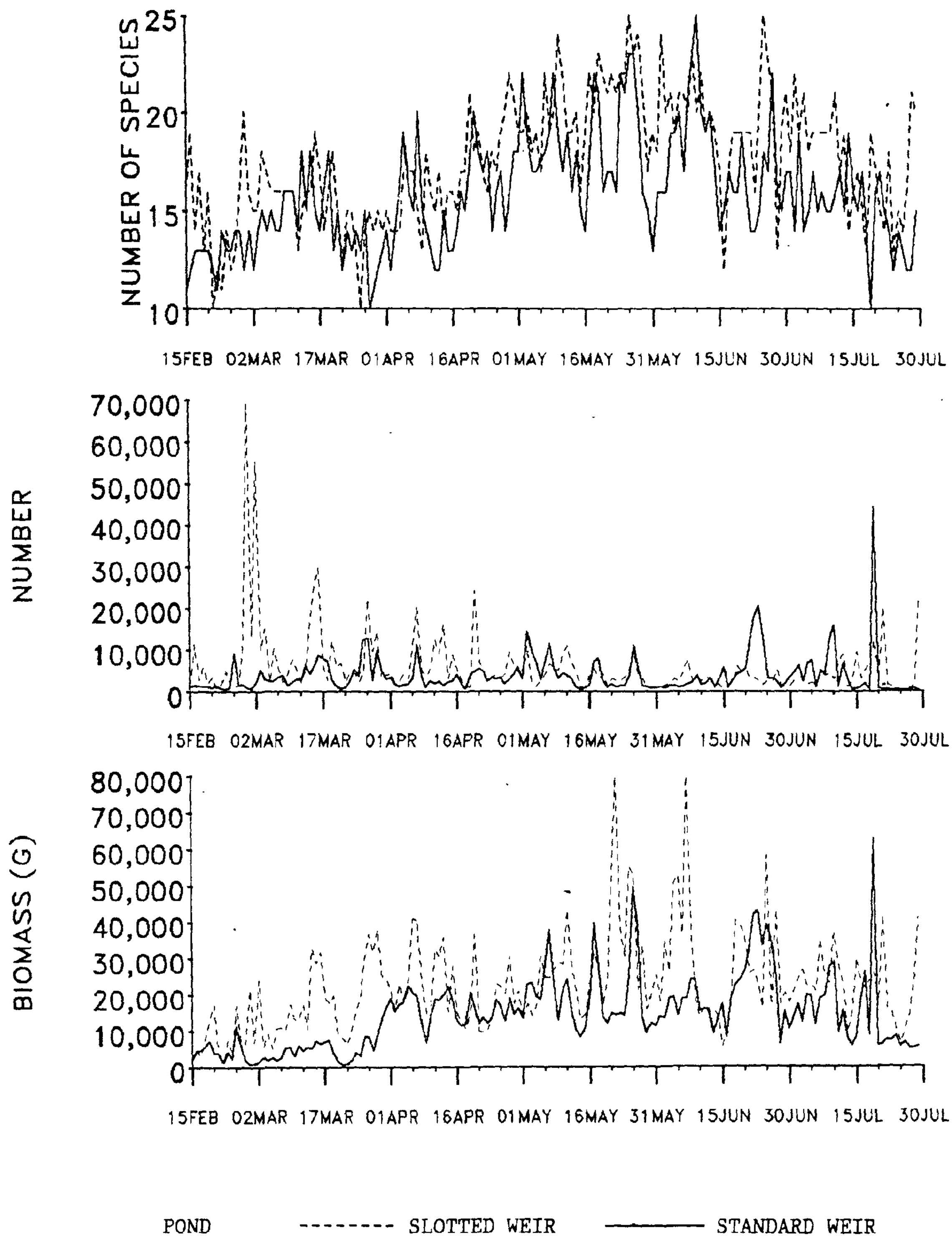


Figure 7. Number of species, total number of individuals, and biomass of all emigrating species taken by the trap in each experimental pond.

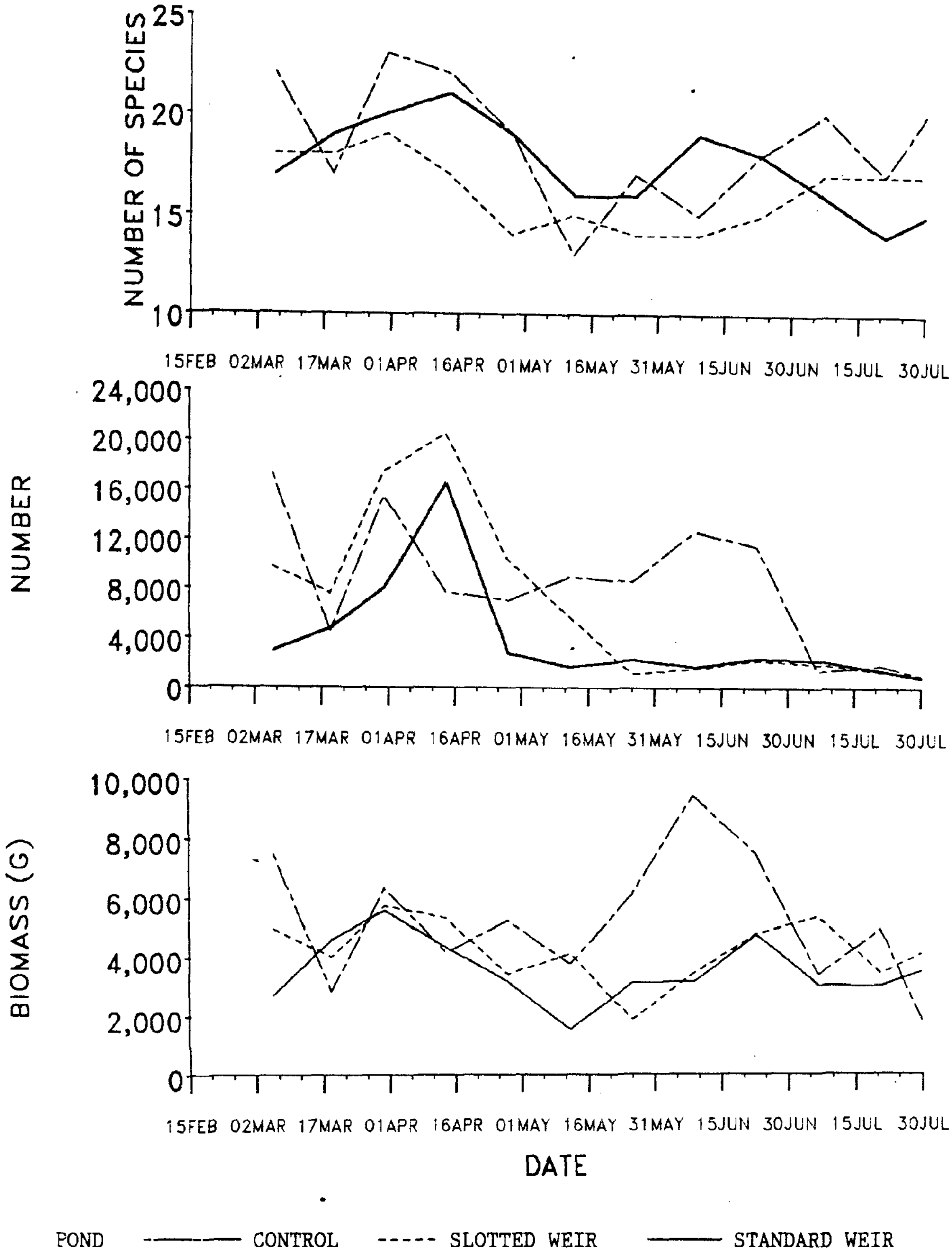


Figure 8. Number of species, total number of individuals, and biomass of all species taken by both trawls combined in each experimental pond.

pond by both numbers and biomass as compared to that from the standard-weir pond (Table 1).

Total trawl catch of most of the economically important species such as gulf menhaden, Atlantic croaker, white shrimp, and brown shrimp was greater in the control and slotted-weir ponds than in the standard-weir pond (Table 3).

Twenty-seven species were taken by the trawls in the standard-weir pond trawl catch, 29 in the slotted-weir, and 46 in the control pond (Table 3). Trawling indicated little difference in number of species between the two experimental ponds, whereas the trapping data indicated 57 species occurred in the slotted-weir pond and 42 in the standard-weir pond. We have no trap data for the control pond, but based on the trawl data, trap catches there would probably have taken more species than taken emigrating from the ponds having either type of weir. Trends in mean weight are presented in Appendix Figs. 1 - 29 and mean weight of organisms captured by the trawls over the entire study are presented in Table 4.

Species Composition Conclusions

1. More organisms (60%) and more biomass (62%) emigrated from the slotted-weir pond than the standard-weir pond during the study period.
2. More species emigrated from the slotted-weir pond (57) than from the standard-weir pond (42) during the study period.
3. The order of species abundance was similar between the two ponds for the study period.
4. Except for striped mullet, which were approximately five times larger in the slotted-weir pond, most economically-important species had a lower mean weight when emigrating from the slotted-weir pond than from the standard-weir pond for the study period.
5. Total trawl catch was higher in the control and slotted-weir ponds than in the standard-weir pond for the study period.
6. More species were taken by the trawls in the control pond (46) as compared to the slotted-weir (29) and standard-weir (27) ponds for the study period.

Table 4. Mean weight (grams) of organisms derived from the combined catch from both trawls for the duration of the study. Values are computed for those species which had a total catch of 10 or greater. Species that were not taken in more than one pond are not included.

SPECIES	STANDARD WEIR	SLOTTED WEIR	CONTROL
male blue crab	34.9	17.9	34.7
immature female crab	14.4	10.0	19.1
pinfish	9.4	7.9	8.4
striped mullet	1.5	6.6	10.8
gulf killifish	3.1	3.2	4.2
brown shrimp	6.4	3.2	1.0
Atlantic croaker	5.7	3.1	2.8
spot	4.4	2.7	1.6
white shrimp	2.7	1.6	0.6
sailfin molly	0.6	1.1	0.7
sheepshead minnow	0.8	1.0	1.4
clown goby	1.1	1.0	
bay anchovy	0.9	0.9	0.3
gulf menhaden	0.6	0.6	0.5
inland silverside	0.8	0.6	0.6
rainwater killifish	0.5	0.5	0.5
diamond killifish	0.4	0.5	
blue crab (less than 25 mm)	0.4	0.5	0.3
naked goby	0.6	0.4	0.5
darter goby	0.8	0.3	
grass shrimp	0.1	0.2	0.2
white mullet	3.8		9.5

Environmental

Salinity

Salinity readings were taken in the experimental ponds at three locations; the environmental stations (just pondward of the chutes), the levee station, and the trawling stations (Figs. 2 and 3). The salinities taken at the environmental stations did not represent the salinity of the entire ponds, especially when the current was incoming. The salinities taken during trawling were more representative of the entire pond because they were taken at different locations within each pond. The levee station was approximately at the midpoint of the middle levee, and readings there nearly equaled the readings of the trawl stations on the days when trawl samples were taken (Fig. 9) and were thus used to represent the experimental pond salinities. Hourly salinity values taken by the Hydrolab instruments (located at the environmental stations) from 17 January 1986 through 30 July 1986 are presented in Appendix Figure 30.

No statistical difference was detected between the two Grand Bayou salinity stations ($P = 0.76$, PROC GLM, SAS Institute 1985), thus the averages of these two readings were used to represent the Grand Bayou salinity. Hereafter, any reference to the Grand Bayou salinity will be to the daily average of salinity at stations A and B.

The salinity in the slotted-weir pond was approximately 1-3 ppt higher than in the standard-weir pond for the first two months of the study (Fig. 10). (The structures were in place approximately two months prior to the beginning of the study, thus the observed differences early in the study were probably due to the structures.) The bottom of the slotted-weir pond had an approximate 0.3-foot higher elevation than the standard-weir pond. Thus, the slotted-weir pond volume was 23 percent less than the standard-weir pond volume when the water levels were at the weir crest level in the ponds. The resultant lower volume in the slotted-weir pond may account for the increase in salinity (1-3 ppt) in that pond early in the study. In addition, if the volumes were the same, the expected differences in salinity and water level would be considerably less than seen in this study.

The higher the water levels in the ponds and Grand Bayou increased

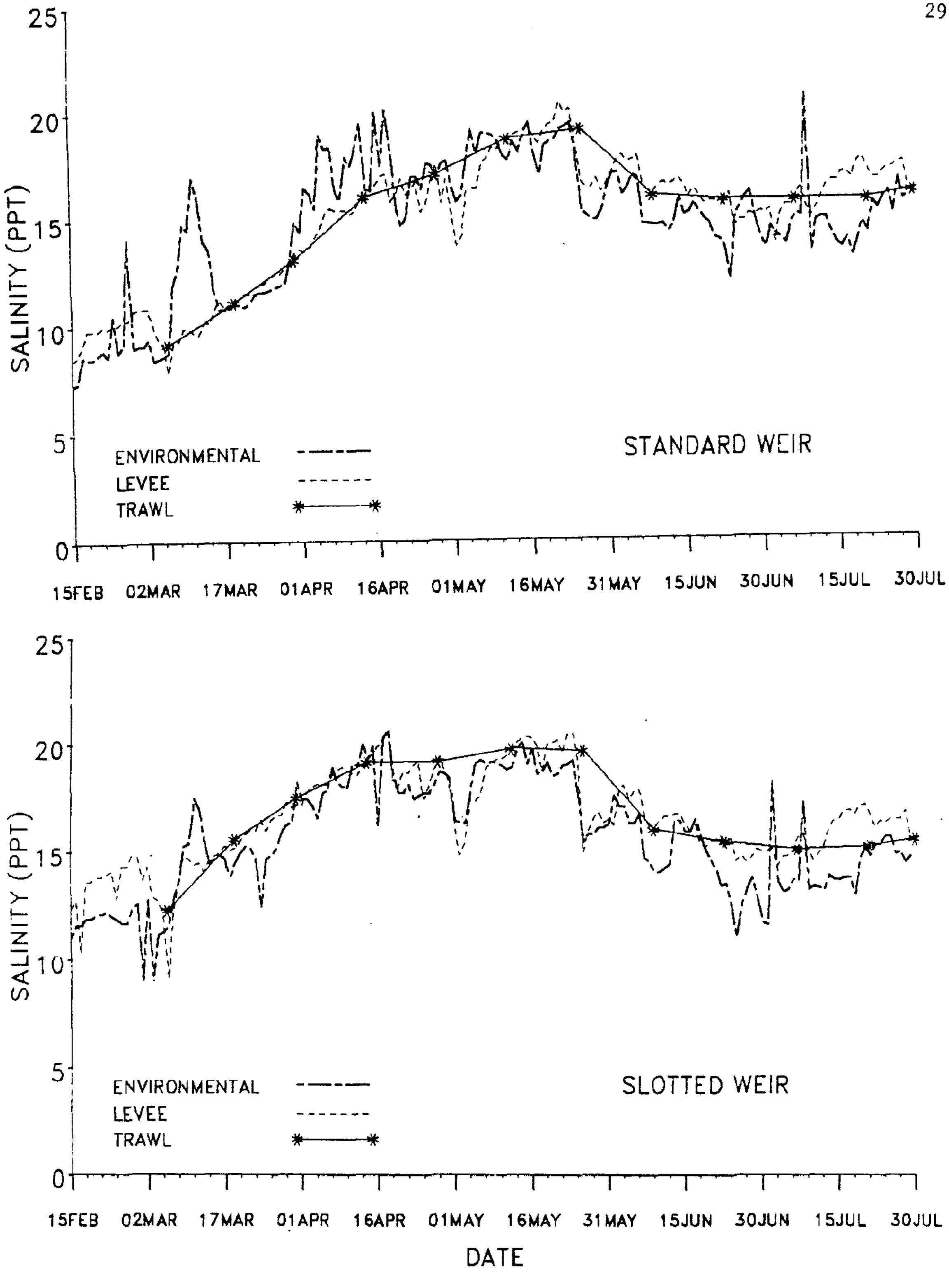


Figure 9. Daily salinity readings taken at the environmental and levee stations, and the mean salinity taken at the trawling stations, for both experimental ponds.

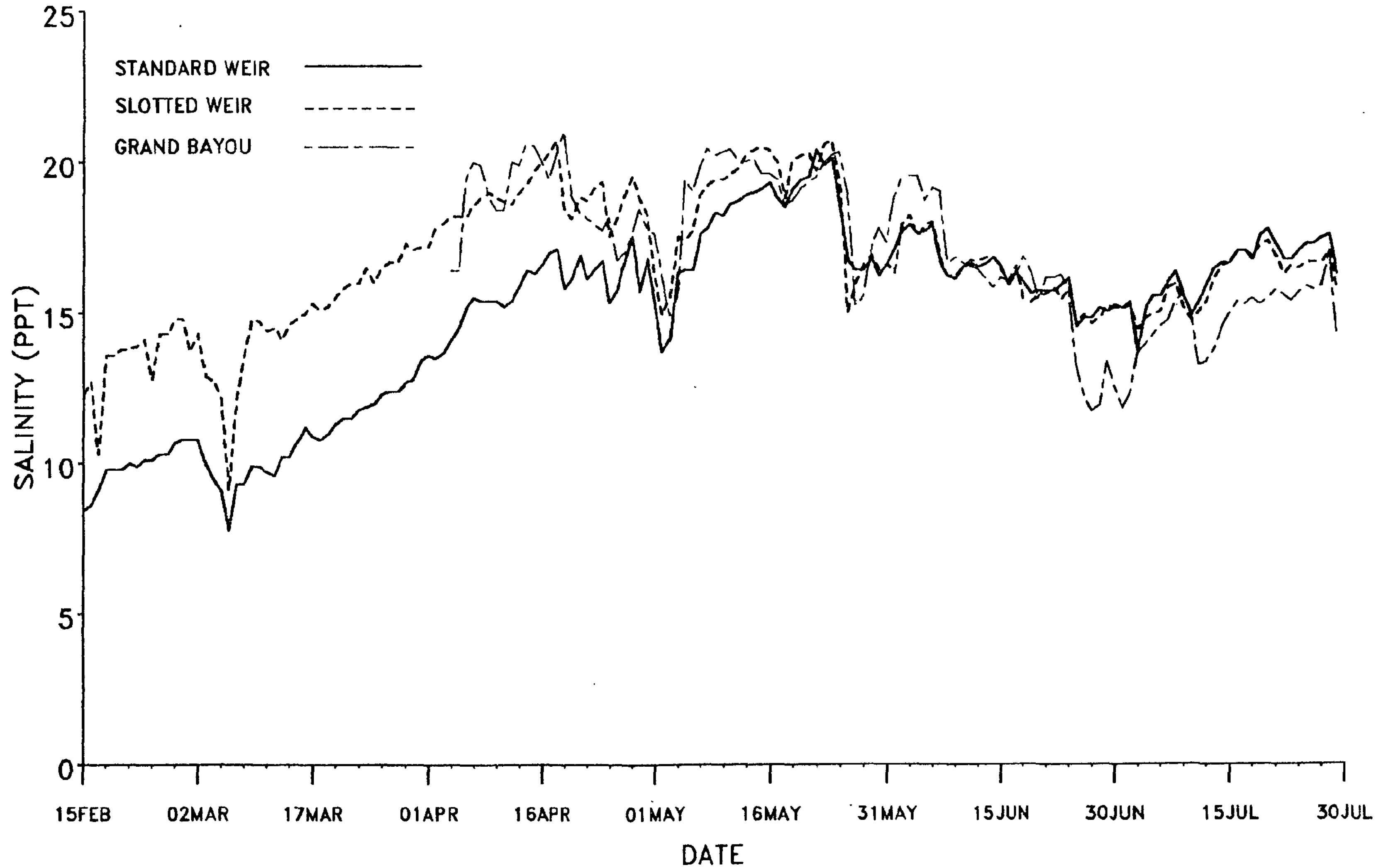


Figure 10. Salinity in both ponds (as measured at the levee stations) and in Grand Bayou (average of stations A and B).

above the weir crest level the more similar both ponds became in terms of salinity and water level (Figs. 10 and 11). To compare salinities for the different locations, the data were separated by concurrent time periods (Table 5). (In Grand Bayou, salinity readings began on 4 April 1986 and water level readings began on 4 March 1986.) Over the entire study period, the slotted-weir pond salinity had a lower standard deviation than the standard-weir pond. The standard-weir pond had lower salinities (which deviated greatly from its mean) in the early part of the study, which accounted for this greater overall deviation. When examining data from 4 April through 30 July 1986, Grand Bayou, the slotted-weir pond and the standard-weir pond had decreasing standard deviations, respectively (Table 5). Salinity taken with trawling indicated that the control pond had the highest standard deviation in salinity and the slotted-weir pond had the lowest. Salinities over the entire year, if not more than one year, would be needed to make any firm conclusions on how these structures affect the salinity regime.

Water Level

The ability to control water levels is of major concern to most marsh managers. Two strong cold fronts lowered the water level in Grand Bayou to -14 inches (0 inches = marsh level) early in the study (Fig. 11, Table 5). The water levels in the slotted-weir pond dropped to a minimum of -8 and -9 inches on these two occasions, whereas the water levels dropped to -5 and -5.5 inches in the standard-weir pond (Fig. 11). If the weir crests in both ponds were to the scale that is normally used (1 foot of weir crest per 70 acres of marsh), then water levels would not have dropped as low in either pond. When the water levels dropped in Grand Bayou, the lowest water levels were reached in the slotted-weir pond before the standard-weir pond. As the water levels rose, the water level in the slotted-weir pond began to rise while the levels were still dropping in the standard-weir pond. Thus for these frontal periods, the slotted-weir would have greater periods of incoming current (traded off with a shorter period of water level decrease), which would allow a greater period of time for larval and/or juvenile organisms to enter the pond. When Grand Bayou water levels were above -6 inches, the pond levels were usually similar. During

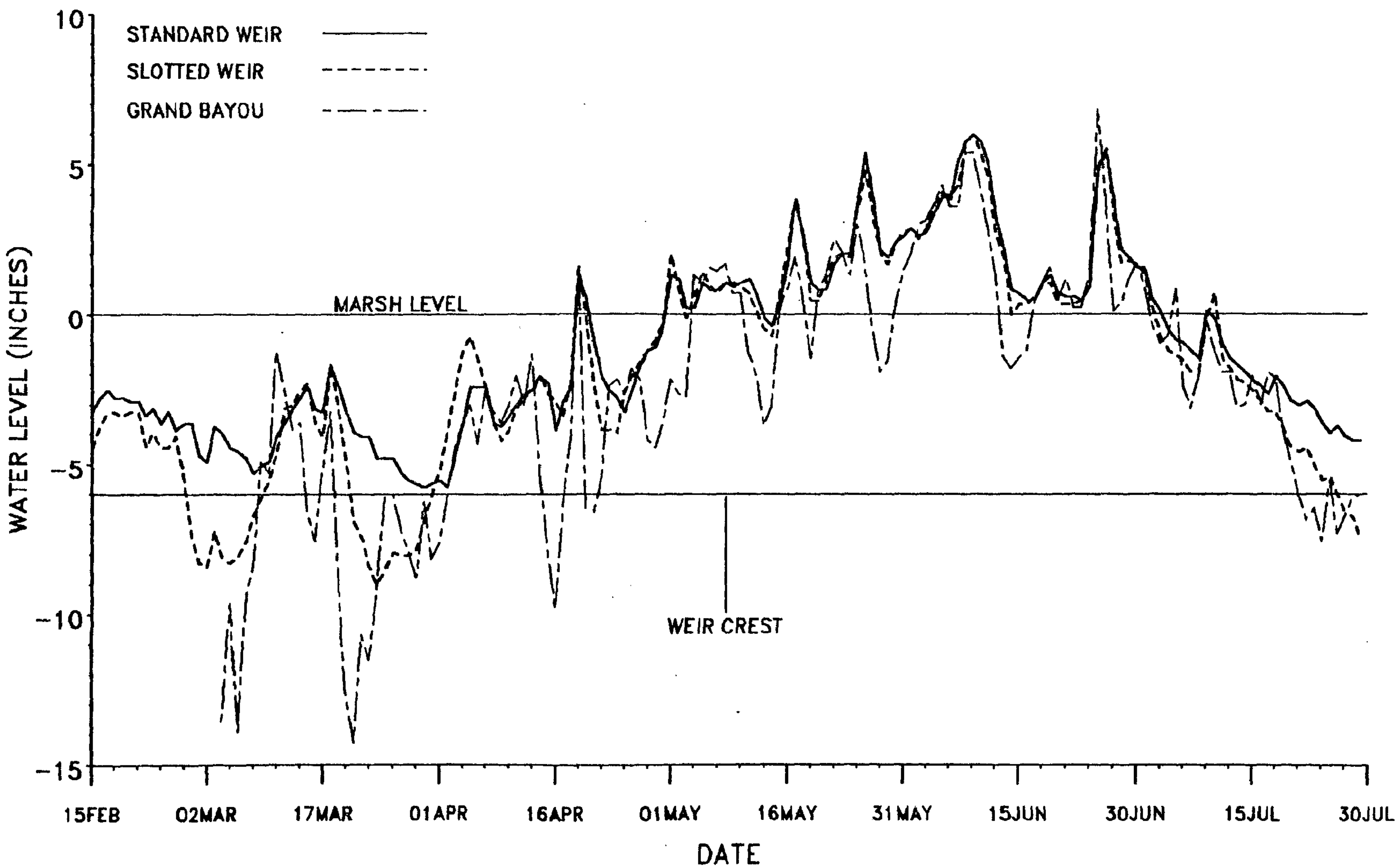


Figure 11. Water level for the experimental ponds and Grand Bayou.

Table 5. Summary statistics for the daily physical measurements for the experimental ponds (at the levee station) and Grand Bayou, and physical data collected while trawling in the three ponds. Data are separated by time frames such that valid comparisons can be made. Water levels are presented in inches, with 0 inches being equal to marsh level.

POND	N (SAMPLES)	MEAN	STANDARD DEVIATION	STD ERROR OF MEAN	MINIMUM VALUE	MAXIMUM VALUE
			15 FEBRUARY - 30 JULY 1987			
			SALINITY (ppt)			
SLOTTED	165	16.6	2.2	0.2	9.1	20.7
STANDARD	165	14.9	3.0	0.2	7.8	20.4
			WATER TEMPERATURE (C)			
SLOTTED	165	23.6	5.2	0.4	8.1	34.7
STANDARD	164	23.5	5.3	0.4	7.1	33.7
			WATER LEVEL (in)			
SLOTTED	165	-1.7	3.6	0.3	-9.0	6.0
STANDARD	165	-1.1	2.9	0.2	-5.8	6.0
			4 MARCH - 30 JULY 1987			
			WATER LEVEL (in)			
GRAND BAYOU	148	-2.5	4.2	0.3	-14.3	6.8
SLOTTED	148	-1.4	3.6	0.3	-9.0	6.0
STANDARD	148	-0.8	3.0	0.2	-5.8	6.0
			4 APRIL - 30 JULY 1987			
			SALINITY (ppt)			
GRAND BAYOU	117	17.1	2.4	0.2	11.7	21.0
SLOTTED	117	17.4	1.8	0.2	14.4	20.7
STANDARD	117	16.6	1.4	0.1	13.7	20.4
			WATER TEMPERATURE (C)			
GRAND BAYOU	117	26.4	3.6	0.3	17.7	32.3
SLOTTED	117	26.0	3.5	0.3	16.0	34.7
STANDARD	117	26.0	3.5	0.3	16.2	33.7
			TRAWLING DATA			
			SALINITY (ppt)			
CONTROL	48	16.2	2.9	0.4	9.1	20.6
SLOTTED	48	16.8	2.3	0.3	12.2	20.3
STANDARD	48	15.3	2.8	0.4	9.1	20.0
			WATER TEMPERATURE (C)			
CONTROL	48	28.3	5.3	0.8	18.0	38.3
SLOTTED	48	27.0	4.6	0.7	17.8	35.8
STANDARD	48	26.8	4.7	0.7	18.2	35.6

extremely low water levels in March, the slotted weir buffered water level changes in range and time as compared to Grand Bayou (Figure 11), but not as much as the standard weir. The short-term drops in water levels from April through July were buffered about the same by both structures. The water levels were slightly more variable over the entire study in the slotted-weir pond than in the standard-weir pond (Table 5). Apparently, as overall water level increased above crest levels, both structures exhibited about the same water level characteristics and only when water levels declined to near crest level did the two structures differ in their water level characteristics. Appendix Figure 31 contains hourly water level values taken by the Leupold-Stevens gauges from 17 January 1986 through 30 July 1986.

Water Temperature

No statistical difference was detected between Stations A and B in Grand Bayou (P = 0.92, PROC GLM, SAS Institute 1985). No obvious differences in water temperature were noticed between the two experimental ponds (Table 5, Appendix Fig. 32) at the levee stations.

Environmental Conclusions

1. Both structures reduced the salinity changes, when compared to Grand Bayou, with the slotted-weir pond having the lower standard deviation than the standard-weir pond for the overall study period (even though the slotted-weir pond had 23% less volume). Data should be collected from all times of one or more years to make firm conclusions on the effect these two structures have on the salinity regime.
2. As Grand Bayou water levels increased above the weir crest level, the experimental ponds became more similar in water level and salinity for this study period at least.
3. Water levels in the slotted-weir pond were 3 to 4 inches lower than the standard-weir pond when water levels were extremely low in Grand Bayou (-14 inches), but similar between the experimental ponds when water levels were above the weir crest.

4. No obvious differences in water temperatures were detected between the two experimental ponds and Grand Bayou for the study period.

GENERAL DISCUSSION

Each marsh management situation may differ in terms of the marsh type, location relative to the Gulf, desired resource use, and funds available for management. Any type of marsh management will require a trade off of time, money, and certain natural resources. Historically, weirs have been installed primarily to maintain minimum water levels for human access and improve habitat for waterfowl and furbearers. Recently these weirs have been recommended to reduce saltwater intrusion and erosion (Davis and Gagliano 1983). There is no direct evidence that weirs reduce erosion, and only in certain hydrological situations do they reduce saltwater intrusion. Herke et al. (1987b) demonstrated the fisheries losses due to weir construction. Chabreck and Hoffpauir (1965), Chabreck (1968), and Wicker et al. (1983) discussed the benefits of weirs to furbearers and waterfowl. Reduced growth of saltmarsh cordgrass in water-logged soils (a condition often found in semi-impounded areas) has been demonstrated by Mendelssohn and Seneca (1980) and Mendelssohn et al. (1980). The resource manager must consider these and possibly other aspects when making marsh management decisions. Thus, the purpose of this study was to test the effects of a management alternative that would improve estuarine-dependent fisheries production, thereby providing an additional aspect for managerial consideration.

The slotted weir allowed the emigration of 241% more brown shrimp and 82% more brown shrimp biomass than the standard weir. Although the complete annual cycle of most other species was not covered by the study, the total catch of all emigrating species was 60% higher (62% by biomass) in the slotted-weir pond. Although the total biomass of emigrants was less, the average size of an economically-important organism (with the major exception of striped mullet) was larger in the standard-weir pond.

Comparison of the results of this study to that of Herke et al. (1987b) allows a look at four structural alternatives, all monitored at the same study site: standard weir, slotted weir, standard weir set at 12 inches below marsh level, and no structure. The most obvious drawback to the comparison is that the Herke et al. (1987b) data were from years other than the present study. Table 6 presents comparative data (15 February through 30 July) on these four structures. It is obvious that the most fisheries export would generally occur with no structure. Comparison of brown shrimp catch by date for the four structures indicates that the absence of a structure allows the greatest emigration, while the standard fixed-crest weir allows the least (Fig. 12). Since any type of structure placed in the path of these migrating organisms apparently impedes movement, the objective of this study was to examine an alternative to the fixed-crest weir in the coastal habitat, which would more adequately balance the resource use for all forms of wildlife.

The slotted-weir appears to be a compromise (between no weir and a standard weir) for both fisheries and hydrologic balance. The slotted weir apparently yields median results between the control pond (early and abundant immigration, early emigration, low mean size, and high rate of cycling) and the standard weir (later and less abundant immigration, delayed emigration, increasingly greater mean size, and low rate of cycling). Although the hydrologic data in this study only cover parts of the winter and summer regime, it appears the greater discrepancy in hydrology between the ponds would occur in the winter, especially during cold fronts. (A possible management practice may be to close the slot during strong cold fronts.) The effect of the slotted and standard weir for management of the hydrologic regime should be further studied and should encompass the entire annual cycle.

The width of the slot would be subject to management requirements and the hydrodynamics of the area concerned. The widest slot that will still achieve the rest of the management goals would be desired for coastal fisheries benefits. Data from this study can be used as an example, but not necessarily as a model. With these empirical data and knowledge of hydrologic principles, formulas or models could be derived to estimate the slot width for a given area to meet management criteria. The weir crests (see Methods and Procedure) were wider per area of marsh affected than is generally used in practice. Thus, the absolute differences in salinity and water levels between the two experimental ponds in this study probably were greater than would be expected had the marsh area been larger or the weir crests shorter.

Table 6. Catch of abundant, or economically-important, organisms taken by Herke et al. (1987b)(15 February 1983 through 30 July 1983) and this study (15 February 1986 through 30 July 1986).

Species	Herke et al. (1987b) No Structure	Herke et al. (1987b) Low Standard Weir[1]	This Study Slotted Weir	This Study Standard Weir
gulf menhaden	834,045	73,717	279,171	219,279
grass shrimp	324,767	331,871	388,977	270,907
brown shrimp	285,954	93,486	97,694	28,681
Atlantic croaker	228,296	47,728	34,176	22,193
blue crab (≤ 25 mm)	226,833	151,567	6,576	472
bay anchovy	169,771	22,820	1,970	1,614
imm. female blue crab	97,968	75,259	28,364	9,018
inland silverside	95,648	80,343	36,766	13,451
male blue crab	75,711	60,431	24,874	8,689
spot	16,496	9,022	15,805	4,045
striped mullet	10,603	11,484	12,921	3,560
gulf killifish	6,181	5,184	11,988	6,350
naked goby	5,998	3,033	2,071	1,859
sheepshead minnow	4,795	2,726	7,464	3,540
white mullet	2,141	3,416	21,773	15,902
pinfish	207	155	6,115	529
white shrimp	695	15	2,222	368
red drum	540	80	18	2
sand seatrout	490	135	37	18
southern flounder	30	12	115	13
spotted seatrout	9	0	2	0

[1] Standard weir with crest set 12 inches below average marsh soil level.

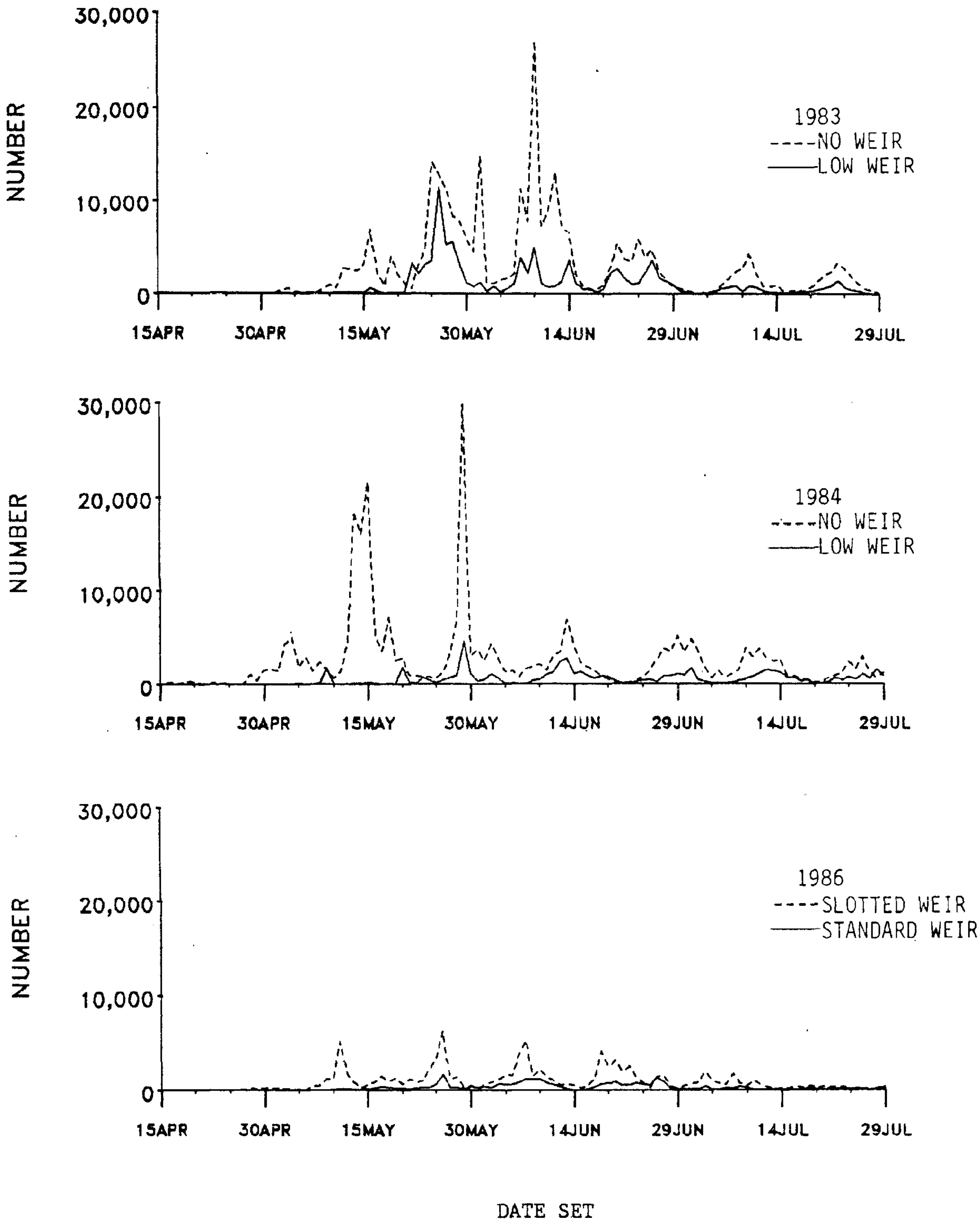


Figure 12. Brown shrimp catch for 1983 and 1984 (Herke et al. 1987b) and 1986 (this study) at the experimental ponds. The weir crest was set at 12 inches below average marsh soil ground level in 1983 and 1984.

Also, the slotted-weir pond had less volume, which should have increased the salinity and water level variability. The length of weir crest, marsh area affected, depth, ratio of marsh to open water, amount of fresh water inflow, and other considerations should be included when calculating the slot width.

If a marsh is to be managed by water-control structures, they should be customized to the specific resource needs. A slotted weir may be inappropriate in a fresh or intermediate marsh, because saltwater exclusion may be the primary management goal. Cowan et al. (1986) found that most marsh management practices in the fresh and intermediate marshes were generally successful. However, they concluded marsh management practices in the brackish to saline habitats were, by and large, only marginally successful. Indications are that the brackish and saline marshes may need more water exchange and fluctuations to allow oxidation of the soils and reduce the stress upon the natural plants that dominate that environment.

From this study it is evident that, if a weir is considered as a coastal marsh management tool, a slotted weir would be more beneficial to fisheries resources. Additional research should be conducted to determine the compatibility of slotted weirs with management goals which are designed to benefit other forms of wildlife, and preserve and enhance marsh vegetation. As a minimum, such investigations should:

1. Evaluate the effectiveness of the standard and slotted weir in reducing erosion and stress on the native plants.
2. Evaluate the effectiveness of these structures in providing habitat for other forms of wildlife.
3. Further evaluate the effect of these structures on seasonal salinity patterns and water levels.
4. Evaluate the effect of these structures on other estuarine-dependent fishes and crustaceans (the target species for this study was brown shrimp).

These evaluations could be done simultaneously to reduce costs. They should also cover enough years (probably 5 to 7) to provide a complete evaluation of the short- and long-term effects of alteration of the hydrologic regime on the marsh vegetation and all forms of wildlife.

General Conclusion

1. The slotted weir allowed greater numbers and biomass of brown shrimp to emigrate back toward the Gulf. Resource managers should consider the slotted weir as an alternative to the standard fixed-crest weir.

CONCLUSIONS

The conclusions for each section are reproduced here for convenience of the reader. The study only covered a 5.5 month period (15 February through 30 July), thus these conclusions are based on that period alone. Conclusions for species other than brown shrimp (target species for this study) and hydrologic factors would require a study which at least examines an entire yearly cycle.

Brown Shrimp Conclusions

1. The slotted weir allowed more individuals (241% more) and biomass (84% more) of brown shrimp to emigrate back towards the Gulf than did the standard weir.
2. Brown shrimp emigrated from the standard-weir pond later, and at a larger size, than from the slotted-weir pond.
3. Recruitment into the nursery and emigration were delayed and reduced by both structures, but more so by the standard weir.
4. Both structures reduced the cycling of brown shrimp in and out of the marsh nursery with the standard weir reducing it more.
5. Use of a slotted weir should result in more brown shrimp production than would use of a standard weir.

Composite Species Conclusions

1. More organisms (60%) and more biomass (62%) emigrated from the slotted-weir pond than the standard-weir pond during the study period.
2. More species emigrated from the slotted-weir pond (57) than from the standard-weir pond (42) during the study period.
3. The order of species abundance was similar between the two ponds for the study period.

4. Except for striped mullet, which were approximately 5 times larger in the slotted-weir pond, most economically-important species had a lower mean weight when emigrating from the slotted-weir pond than from the standard-weir pond for the study period.
5. Total trawl catch was higher in the control and slotted-weir ponds than in the standard-weir pond for the study period.
6. More species were taken by the trawls in the control pond (46) as compared to the slotted-weir (29) and standard-weir (27) ponds for the study period.

Environmental Conclusions

1. Both structures reduced the salinity changes, when compared to Grand Bayou, with the slotted-weir pond having the lower standard deviation than the standard-weir pond for the overall study period (even though the slotted-weir pond had 23% less volume). Data should be collected from all times of one or more years to make firm conclusions on the effect these two structures have on the salinity regime.
2. As Grand Bayou water levels increased above the weir crest level, the more the experimental ponds became similar in water level and salinity for the study period.
3. Water levels in the slotted-weir pond were 3 to 4 inches lower than the standard-weir pond when water levels were extremely low in Grand Bayou (-14 inches), but similar between the experimental ponds when water levels were above the weir crest.

General Conclusion

1. The slotted weir allowed greater numbers and biomass of brown shrimp to emigrate back toward the Gulf. Resource managers should consider the slotted weir as an alternative to the standard fixed-crest weir.

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Appendix Table 1. Analysis of variance (PROC GLM, SAS 1985) for brown shrimp (log number + 1) for trawling data. Date is further analyzed by its' linear (D), quadratic (D*D), and cubic (D*D*D) components.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: log catch + 1

SOURCE	DF	SUM OF SQUARES (TYPE I)	F VALUE	PR > F		R-SQUARE
MODEL	111	300.29	9.17	0.0001	**	0.98
POND	2	41.34	70.05	0.0001	**	
LOCATION	1	0.02	0.05	0.8229		
D	1	0.02	0.07	0.8004		
D*D	1	91.25	309.26	0.0001	**	
D*D*D	1	1.74	5.89	0.0248	*	
DATE	7	6.69	3.24	0.0183	*	
POND*LOCATION	2	0.03	0.05	0.9488		
D*POND	2	67.47	114.34	0.0001	**	
D*D*POND	2	4.33	7.34	0.0041	**	
D*D*D*POND	2	0.44	0.74	0.4907		
POND*DATE	14	12.78	3.09	0.0106	*	
LOCATION*DATE	10	1.86	0.63	0.7718		
POND*LOCATION*DATE	20	5.62	0.95	0.5423		
GEAR	1	12.39	41.98	0.0001	**	
POND*GEAR	2	0.59	1.00	0.3870		
LOCATION*GEAR	1	0.13	0.46	0.5077		
GEAR*DATE	10	29.76	10.09	0.0001	**	
POND*GEAR*DATE	20	21.71	3.68	0.0027	**	
POND*LOCATION*GEAR	2	0.69	1.13	0.3417		
LOCATION*GEAR*DATE	10	1.46	0.50	0.8731		
ERROR	20	5.90				
CORRECTED TOTAL	131	306.19				

Appendix Table 2. List of all species, catch and biomass for the entire study taken by the traps and trawls combined.

SCIENTIFIC NAME	COMMON NAME	NUMBER	BIOMASS (G)
Palaemonetes sp.	grass shrimp	761,612	291,776
Brevoortia patronus	gulf menhaden	566,330	539,085
Penaeus aztecus	brown shrimp	132,466	706,896
Menidia beryllina	inland silverside	66,968	56,890
Micropogonias undulatus	Atlantic croaker	59,771	419,705
C. sapidus, immature female	immature female blue crab	37,750	827,757
Mugil curema	white mullet	37,725	276,877
Callinectes sapidus, male	male blue crab	33,926	1,834,874
Leiostomus xanthurus	spot	31,471	106,798
Fundulus grandis	gulf killifish	18,417	80,655
Mugil cephalus	striped mullet	17,542	709,449
Cyprinodon variegatus	sheepshead minnow	11,103	15,520
Anchoa mitchilli	bay anchovy	10,883	7,833
Adinia xenica	diamond killifish	8,291	3,664
Lagodon rhomboides	pinfish	8,035	84,240
Callinectes sapidus	blue crab (less than 25 mm)	7,123	2,896
Penaeus setiferus	white shrimp	6,967	14,220
Poecilia latipinna	sailfin molly	4,765	5,687
Gobiosoma bosci	naked goby	4,308	2,757
Gobionellus boleosoma	darter goby	3,382	2,998
Lucania parva	rainwater killifish	2,704	1,546
C. sapidus, mature female	mature female blue	770	134,902
Citharichthys spilopterus	bay whiff	610	5,815
Gobionellus hastatus	sharptail goby	421	6,182
Symphurus plagiusa	blackcheek tonguefish	416	4,121
Fundulus pulvereus	bayou killifish	191	235
Myrophis punctatus	speckled worm eel	187	2,088
Paralichthys lethostigma	southern flounder	154	21,024
Microgobius gulosus	clown goby	145	143
Gambusia affinis	mosquitofish	124	62
Elops saurus	ladyfish	111	782
Rithropanopeus harisii	mud crab	96	25
Elops saurus leptocephalus	ladyfish leptocephalus	74	7
Cynoscion arenarius	sand seatrout	72	1,344
Sphoeroides parvus	least puffer	58	103
Syngnathus sp.	pipefish	47	54
Membras martinica	rough silverside	34	73
Sciaenops ocellatus	red drum	22	4,258
Lepomis microlophus	redear sunfish	22	188
Pogonias cromis	black drum	12	581
Caranx hippos	crevalle jack	12	46
Microgobius thalassinus	green goby	12	5
Arius felis	hardhead catfish	9	1,421
Dorosoma petenense	threadfin shad	7	25
Archosargus probatocephalus	sheepshead	7	71

Appendix Table 2. continued.

SCIENTIFIC NAME	COMMON NAME	NUMBER	BIOMASS (G)
Cynoscion nebulosus	spotted seatrout	6	88
Dorosoma cepedianum	gizzard shad	6	64
Bairdiella chrysoura	silver perch	5	34
Oligoplites saurus	leatherjacket	5	4
Fundulus similis	longnose killifish	5	52
Synodus foetens	inshore lizard fish	4	241
Pomatomus saltatrix	bluefish	3	2
Gobioides broussoneti	violet goby	3	331
Trichiurus lepturus	Atlantic cutlassfish	3	290
Malaclemys terrapin	diamondback terrapin	2	516
Syngnathus louisianae	chain pipefish	2	9
M. punctatus leptocephalus	worm eel leptocephalus	2	40
Porichthys plectrodon	Atlantic midshipman	1	3
Orthopristis chrysoptera	pigfish	1	1
Alpheus sp.	snapping shrimp	1	2
Uca sp.	fiddler crab	1	2
Harengula jaguana	scaled sardine	1	1
Chaetodipterus faber	Atlantic spadefish	1	17
Lepomis macrochirus	bluegill	1	5
Dormitator maculatus	fat sleeper	1	5
TOTAL		1,835,209	6,177,464

Appendix Table 3. List of species, total catch, and total biomass for trawling data by station and gear for the entire study.

Station WB (standard-weir, back - six-foot trawl)

SPECIES	NUMBER	BIOMASS (g)
grass shrimp	18,854	2,121
gulf menhaden	2,300	733
inland silverside	2,136	1,578
striped mullet	499	380
spot	256	390
bay anchovy	229	166
naked goby	129	68
rainwater killifish	122	60
white shrimp	114	101
brown shrimp	87	244
pinfish	73	26
sailfin molly	45	27
immature female crab	26	302
diamond killifish	24	10
sheepshead minnow	23	22
male blue crab	22	230
blue crab (less than 25 mm)	14	5
gulf killifish	13	46
white mullet	12	14
pipefish	12	14
Atlantic croaker	7	33
clown goby	7	8
mosquitofish	5	3
ladyfish	5	1
darter goby	3	3
ladyfish leptocephalus	3	0
diamondback terrapin	1	45
redear sunfish	1	6
sharptail goby	1	1
TOTAL	25,023	6,634

Station WB (standard-weir, back - sixteen-foot trawl)

SPECIES	NUMBER	BIOMASS (g)
gulf menhaden	1,114	1,011
Atlantic croaker	482	2,474
brown shrimp	388	3,008
spot	340	1,736
inland silverside	324	294
grass shrimp	261	63
white shrimp	197	851
bay anchovy	192	168
pinfish	181	1,864
male blue crab	76	2,920
immature female crab	72	1,014
white mullet	4	37
striped mullet	3	301
blue crab (less than 25mm)	3	1
naked goby	3	4
darter goby	2	2
clown goby	2	3
ladyfish	2	16
pipefish	1	1
TOTAL	3,647	15,771

Station WM (standard-weir, mouth - six-foot trawl)

SPECIES	NUMBER	BIOMASS (g)
grass shrimp	10,203	1,833
inland silverside	2,589	1,842
gulf menhaden	518	176
bay anchovy	213	204
brown shrimp	127	230
naked goby	50	34
white shrimp	49	17
spot	46	108
striped mullet	44	55
rainwater killifish	37	20
pinfish	37	16
sailfin molly	32	18
diamond killifish	22	8
immature female crab	13	132
male blue crab	10	78
darter goby	10	5
Atlantic croaker	8	7
sheepshead minnow	8	4
gulf killifish	7	17
blue crab (less than 25mm)	6	3
clown goby	4	3
pipefish	3	2
mosquitofish	1	0
ladyfish leptocephalus	1	0
ladyfish	1	2
TOTAL	14,039	4,817

Station WM (standard-weir, mouth - sixteen-foot trawl)

SPECIES	NUMBER	BIOMASS (g)
gulf menhaden	2,512	1,640
inland silverside	704	640
Atlantic croaker	422	2,714
spot	363	2,231
brown shrimp	277	2,133
grass shrimp	265	65
bay anchovy	203	212
pinfish	186	2,592
white shrimp	80	223
male blue crab	38	1,862
immature female crab	25	511
clown goby	7	7
white mullet	6	32
striped mullet	2	77
spotted seatrout	1	43
rainwater killifish	1	1
redear sunfish	1	14
darter goby	1	2
naked goby	1	0
ladyfish	1	10
	5,096	15,010

Appendix Table 3. continued.

Station EB (slotted-weir, back - six-foot trawl)

SPECIES	NUMBER	BIOMASS (g)
grass shrimp	21,100	3,202
inland silverside	1,671	939
gulf menhaden	1,226	488
white shrimp	430	198
spot	291	319
rainwater killifish	250	107
brown shrimp	206	483
Atlantic croaker	99	166
bay anchovy	74	53
naked goby	70	19
pinfish	36	61
male blue crab	31	311
immature female crab	25	252
striped mullet	19	137
darter goby	14	4
sheepshead minnow	12	10
gulf killifish	11	31
clown goby	11	9
blue crab (less than 25mm)	10	5
ladyfish	6	1
diamond killifish	2	1
white mullet	2	31
sailfin molly	2	3
TOTAL	25,598	6,833

Station EB (slotted-weir, back - sixteen-foot trawl)

SPECIES	NUMBER	BIOMASS (g)
gulf menhaden	3,729	3,020
spot	1,036	2,910
Atlantic croaker	653	2,176
brown shrimp	369	1,374
white shrimp	336	990
grass shrimp	321	66
inland silverside	264	220
pinfish	246	1,989
bay anchovy	188	161
male blue crab	87	1,705
immature female crab	85	651
striped mullet	19	1,080
clown goby	4	4
blue crab (less than 25 mm)	3	2
southern flounder	3	285
blackcheek tonguefish	3	33
least puffer	2	8
naked goby	2	1
spotted seatrout	1	21
rainwater killifish	1	1
white mullet	1	14
ladyfish	1	3
TOTAL	7,354	16,717

Station EM (slotted-weir, mouth - six-foot trawl)

SPECIES	NUMBER	BIOMASS (g)
grass shrimp	31,895	5,393
inland silverside	4,017	2,429
gulf menhaden	2,512	951
white shrimp	283	173
striped mullet	264	99
rainwater killifish	259	121
bay anchovy	187	157
brown shrimp	179	443
spot	78	131
naked goby	78	28
immature female crab	42	378
gulf killifish	34	113
Atlantic croaker	33	70
sheepshead minnow	29	29
diamond killifish	25	12
male blue crab	20	169
pinfish	11	3
sailfin molly	10	10
darter goby	8	4
blue crab (less than 25mm)	7	3
ladyfish	6	2
mud crab	5	1
mosquitofish	3	1
clown goby	3	2
white mullet	1	12
ladyfish leptocephalus	1	0
southern flounder	1	4
TOTAL	39,991	10,740

Station EM (slotted-weir, mouth - sixteen-foot trawl)

SPECIES	NUMBER	BIOMASS (g)
gulf menhaden	2,922	1,969
spot	1,185	3,640
grass shrimp	582	127
inland silverside	537	501
Atlantic croaker	508	1,565
brown shrimp	408	1,387
pinfish	372	3,223
white shrimp	292	792
bay anchovy	192	183
immature female crab	45	681
male blue crab	43	1,049
rainwater killifish	11	5
striped mullet	10	741
clown goby	7	9
naked goby	7	6
white mullet	3	23
southern flounder	2	3
bay whiff	1	1
sheepshead minnow	1	2
pipefish	1	1
TOTAL	7,129	15,910

Appendix Table 3. continued.

Station CB (control, back - six-foot trawl)

SPECIES	NUMBER	BIOMASS (g)
grass shrimp	9,451	1,664
gulf menhaden	8,862	2,453
white shrimp	1,329	512
brown shrimp	1,121	502
spot	806	639
inland silverside	625	311
bay anchovy	464	149
rainwater killifish	427	203
Atlantic croaker	40	23
striped mullet	29	51
blue crab (less than 25mm)	20	6
ladyfish leptocephalus	16	1
pinfish	15	3
sailfin molly	13	8
sheepshead minnow	11	12
mud crab	7	2
gulf killifish	7	17
mosquitofish	7	1
male blue crab	6	183
white mullet	4	16
darter goby	3	2
naked goby	3	0
chain pipefish	2	9
pipefish	1	0
immature female crab	1	2
clown goby	1	1
TOTAL	23,271	6,773

Station CB (control, back - sixteen-foot trawl)

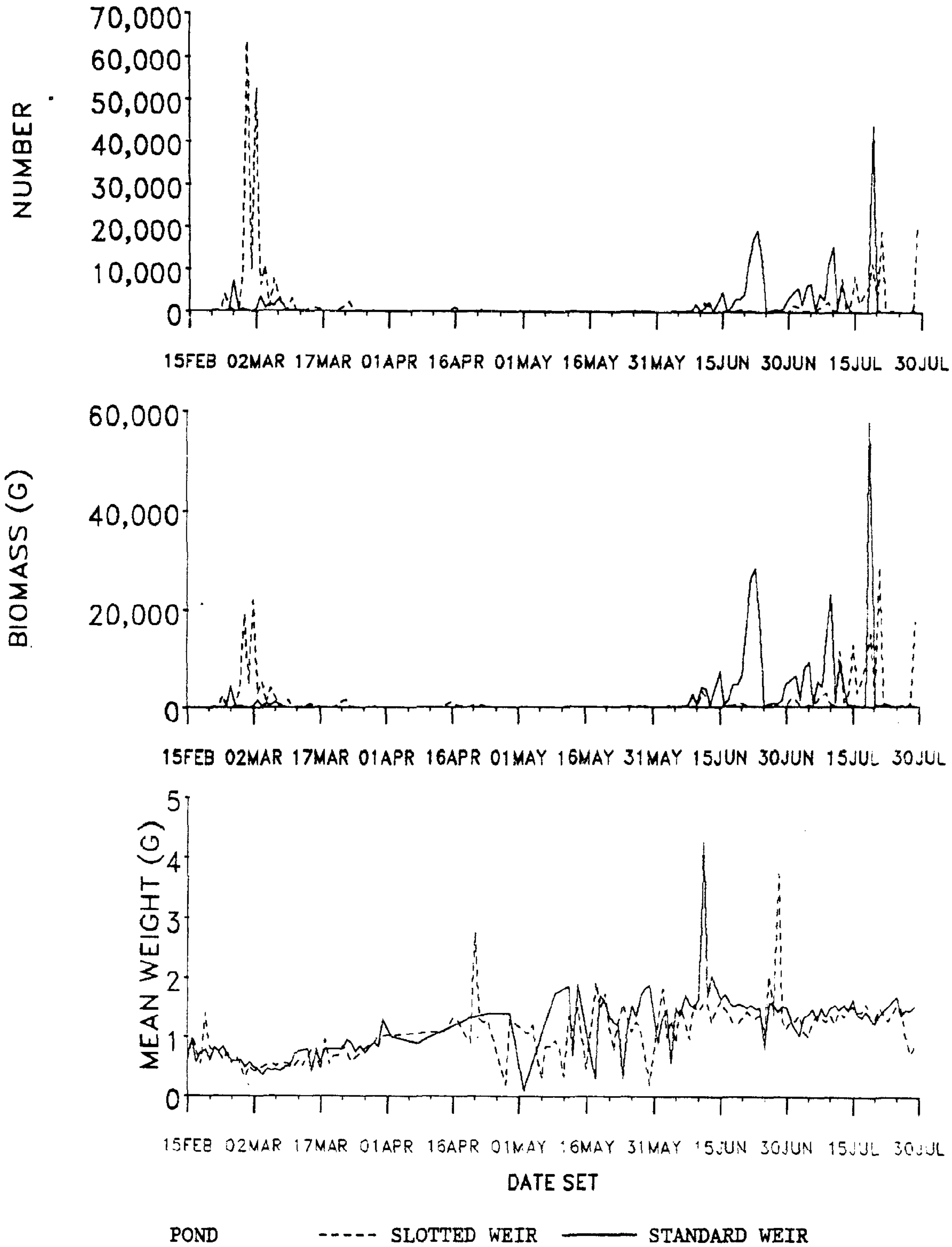
SPECIES	NUMBER	BIOMASS (g)
gulf menhaden	24,811	11,966
spot	4,264	7,190
brown shrimp	959	1,221
grass shrimp	481	81
bay anchovy	374	210
Atlantic croaker	358	1,333
white shrimp	326	292
inland silverside	173	145
pinfish	126	1,259
striped mullet	44	1,519
male blue crab	16	341
mud crab	13	8
immature female crab	13	12
sand seatrout	10	64
white mullet	10	86
southern flounder	10	100
crevalle jack	8	35
naked goby	8	7
rainwater killifish	6	5
threadfin shad	4	17
sheepshead minnow	3	6
redear sunfish	3	22
red drum	2	81
silver perch	2	19
black drum	2	532
sailfin molly	2	2
blue crab (less than 25 mm)	2	1
ladyfish	2	92
spotted seatrout	1	1
hardhead catfish	1	21
least puffer	1	3
diamondback terrapin	1	471
diamond killifish	1	1
pipefish	1	1
darter goby	1	1
TOTAL	32,039	27,146

Station CM (control, mouth - six-foot trawl)

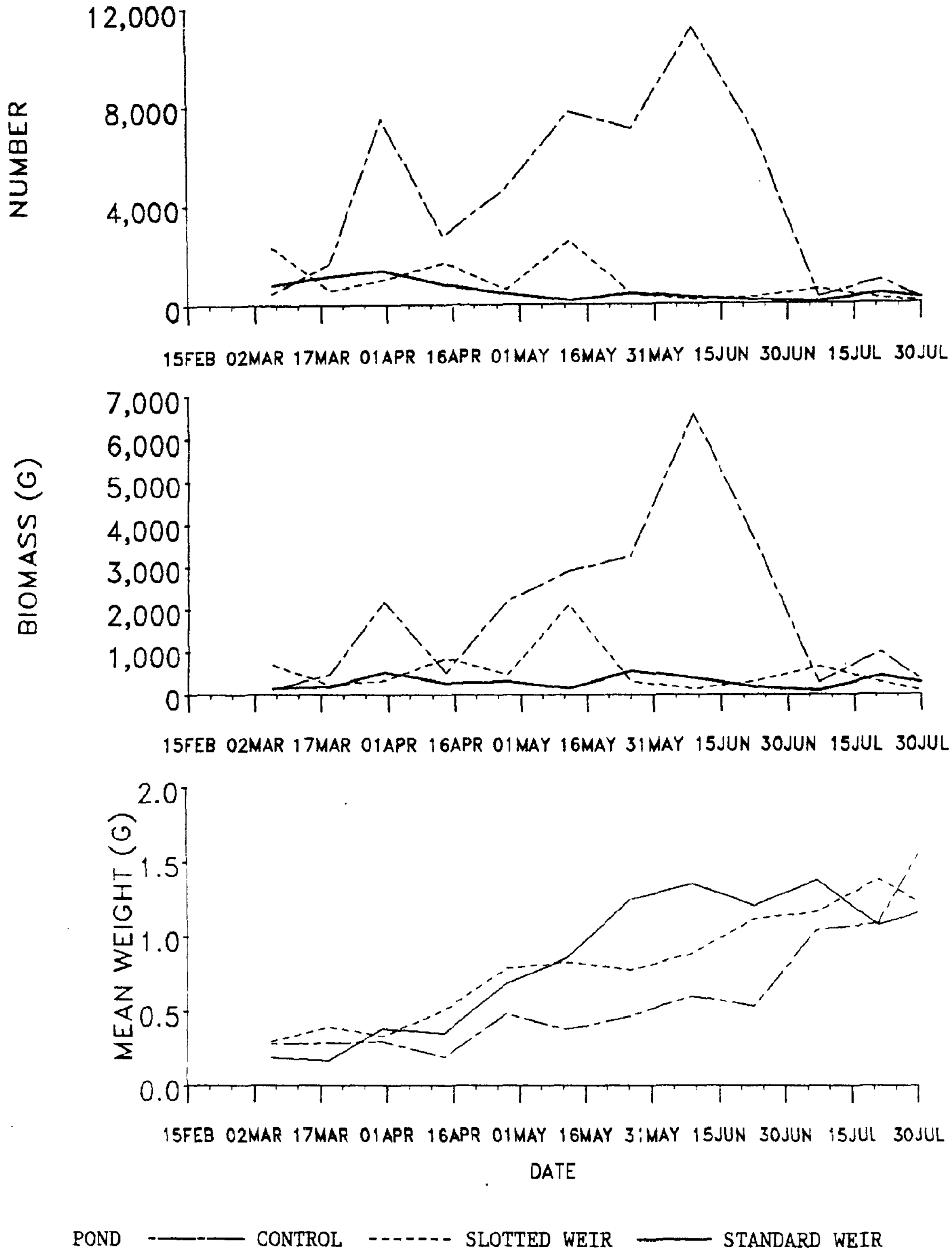
SPECIES	NUMBER	BIOMASS (g)
grass shrimp	8,201	1,958
gulf menhaden	4,816	1,251
inland silverside	3,538	2,238
bay anchovy	3,473	880
brown shrimp	1,051	728
spot	780	644
white shrimp	750	317
rainwater killifish	300	139
Atlantic croaker	285	214
striped mullet	117	92
ladyfish leptocephalus	52	6
pinfish	45	2
naked goby	23	10
rough silverside	21	48
sheepshead minnow	12	18
blue crab (less than 25mm)	10	3
immature female crab	9	15
gulf killifish	7	43
pipefish	7	7
redear sunfish	6	52
southern flounder	2	3
leatherjacket	1	2
pigfish	1	1
scaled sardine	1	1
sailfin molly	1	0
male blue crab	1	7
TOTAL	23,510	8,679

Station CM (control, mouth - sixteen-foot trawl)

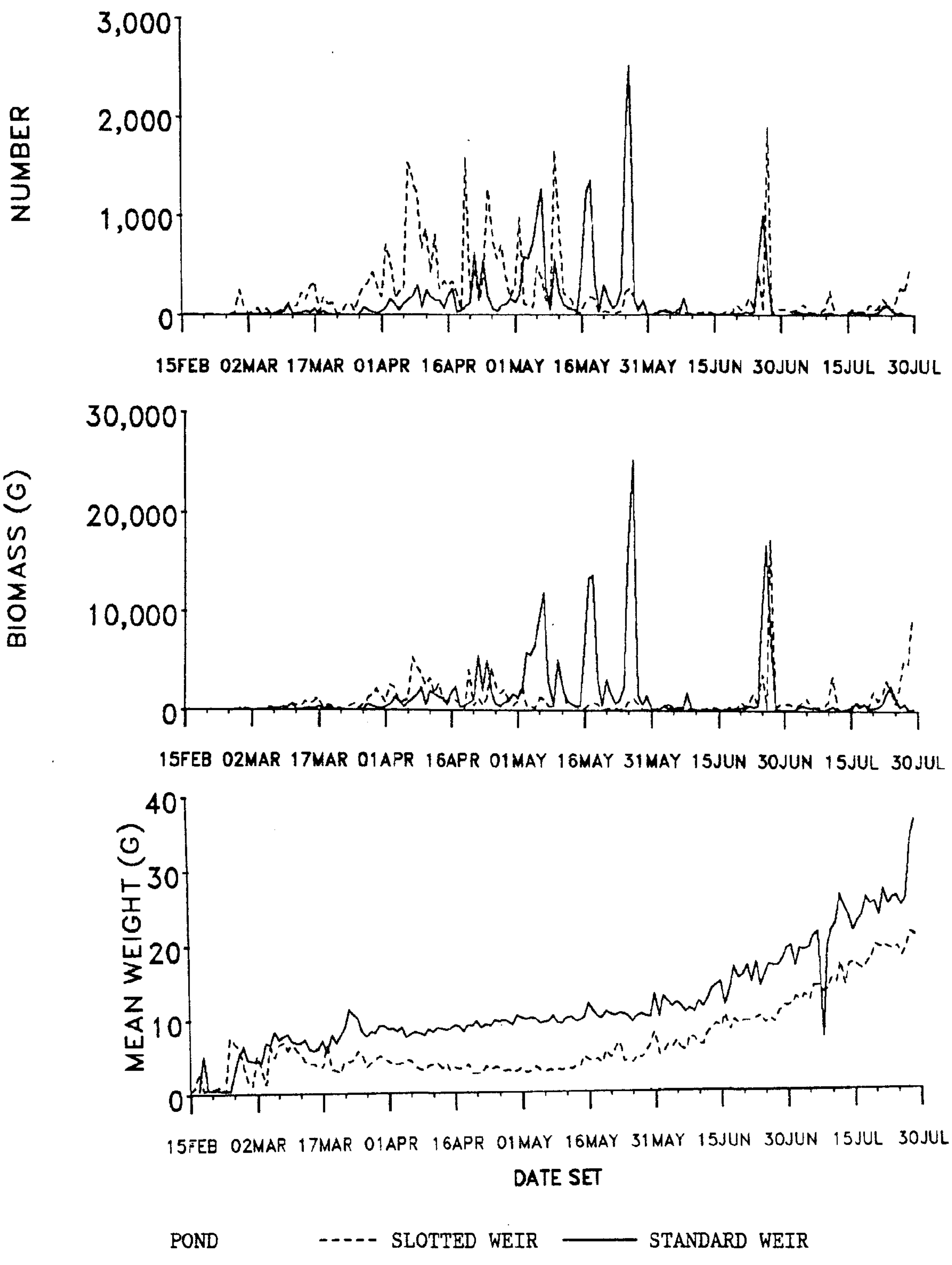
SPECIES	NUMBER	BIOMASS (g)
gulf menhaden	12,558	7,824
spot	2,176	4,605
bay anchovy	1,510	692
brown shrimp	919	1,430
Atlantic croaker	507	1,740
white shrimp	191	316
inland silverside	173	165
grass shrimp	114	24
pinfish	63	821
male blue crab	13	719
immature female crab	12	638
striped mullet	11	500
southern flounder	8	16
sand seatrout	7	36
white mullet	7	97
rough silverside	7	14
least puffer	4	8
naked goby	4	3
crevalle jack	3	9
inshore lizard fish	3	186
mud crab	3	1
rainwater killifish	3	3
leatherjacket	2	2
spotted seatrout	1	2
hardhead catfish	1	10
threadfin shad	1	2
bay whiff	1	1
gizzard shad	1	18
redear sunfish	1	14
darter goby	1	0
green goby	1	1
ladyfish leptocephalus	1	0
blackcheek tonguefish	1	11
TOTAL	18,308	19,906



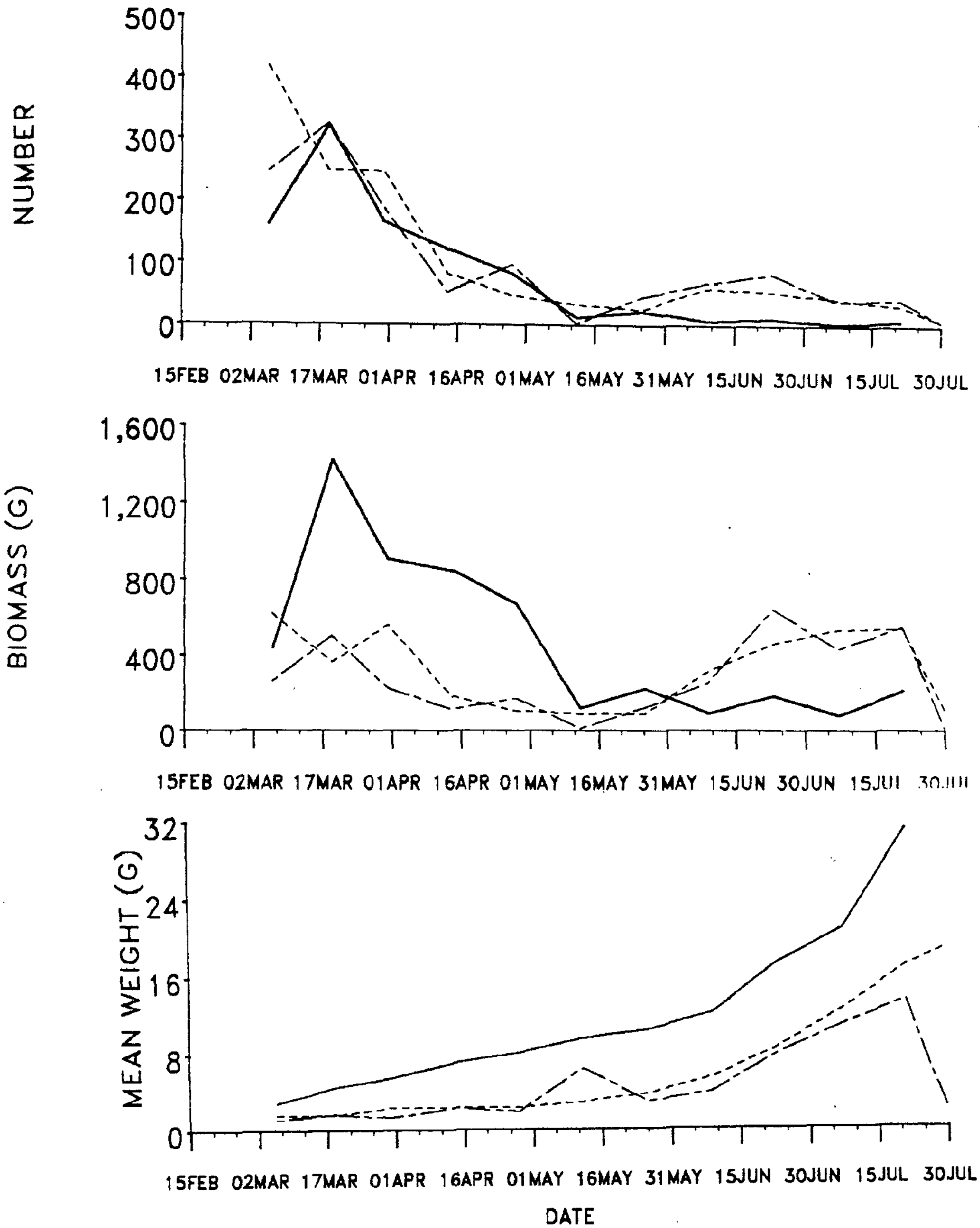
Appendix Figure 1. Number, biomass, and mean weight of gulf menhaden taken by the traps in each experimental pond.



Appendix Figure 2. Number, biomass, and mean weight of gulf menhaden taken by trawls in each pond.

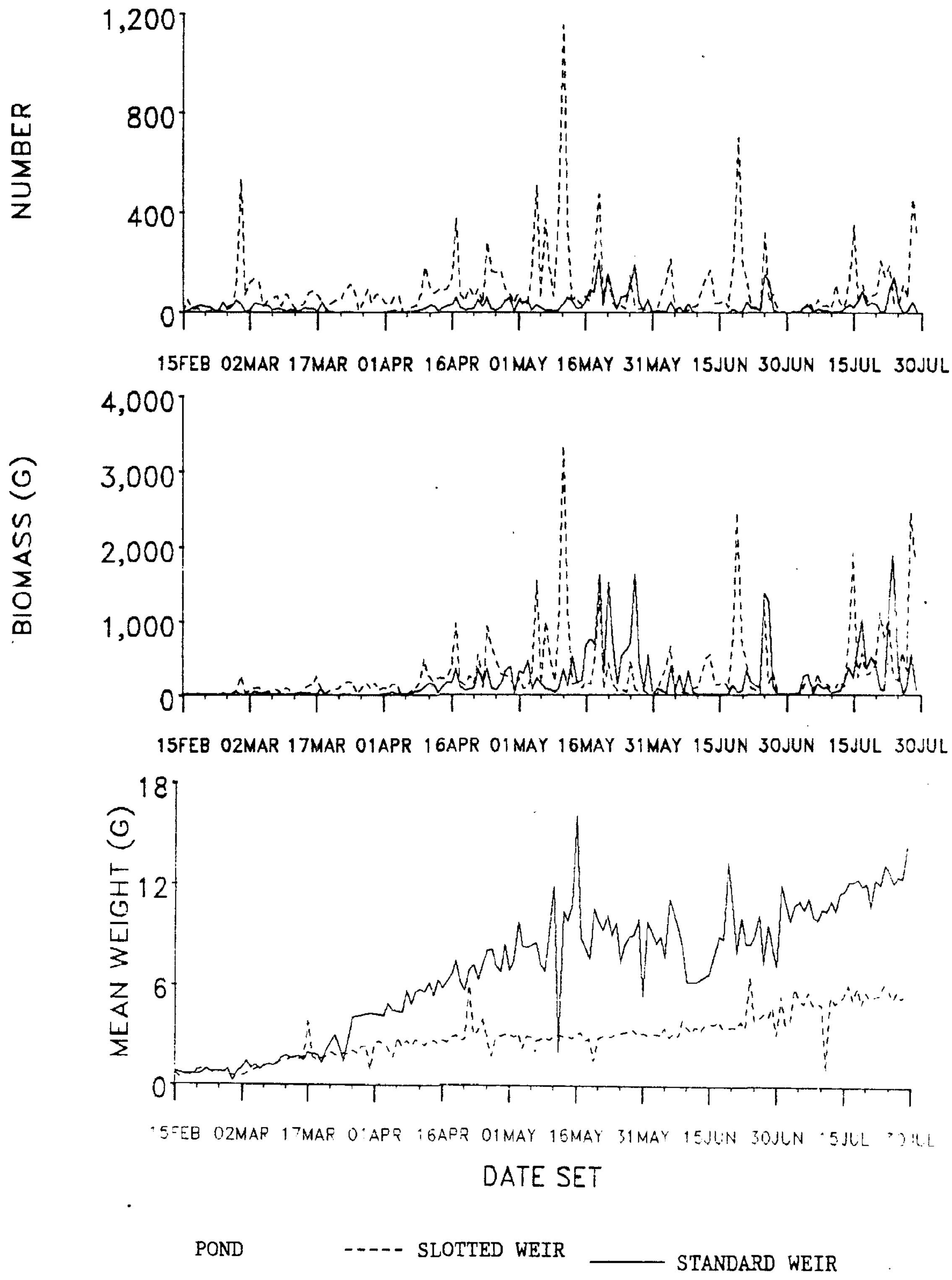


Appendix Figure 3. Number, biomass, and mean weight of Atlantic croaker taken by the traps in each experimental pond.

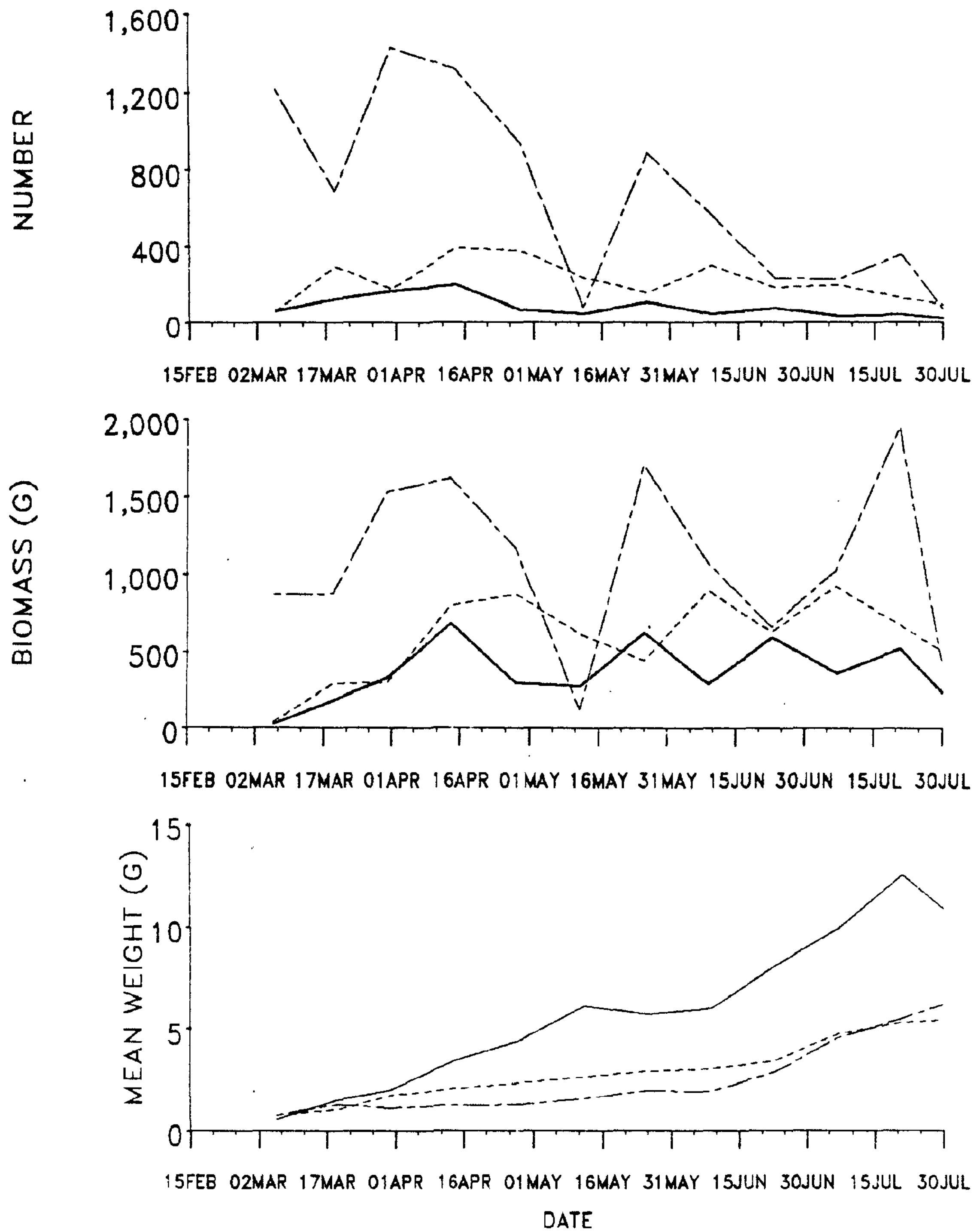


POND ———— CONTROL ------- SLOTTED WEIR ——— STANDARD WEIR

Appendix Figure 4. Number, biomass, and mean weight of Atlantic croaker taken by trawls in each pond.

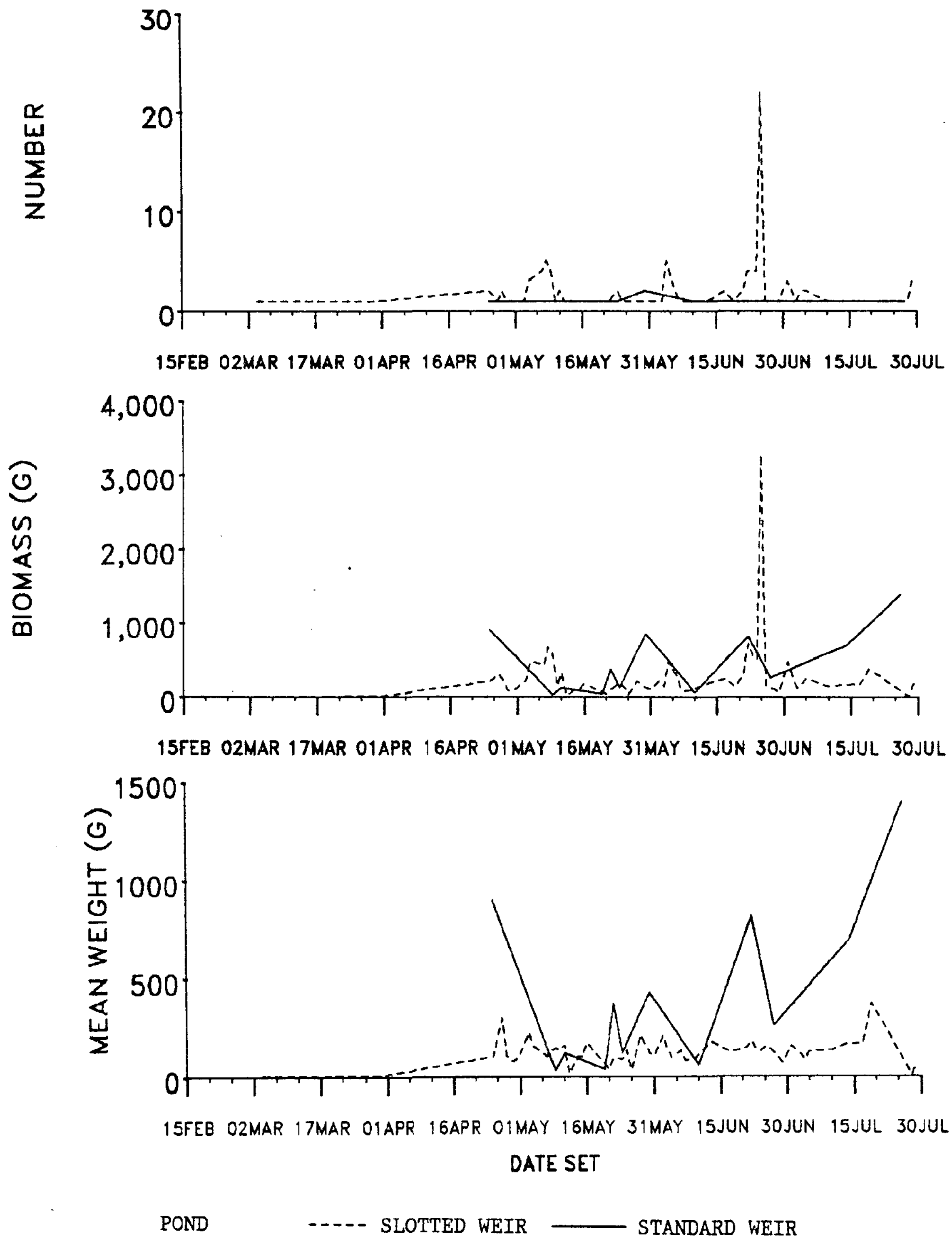


Appendix Figure 5. Number, biomass, and mean weight of spot taken by the traps in each experimental pond.

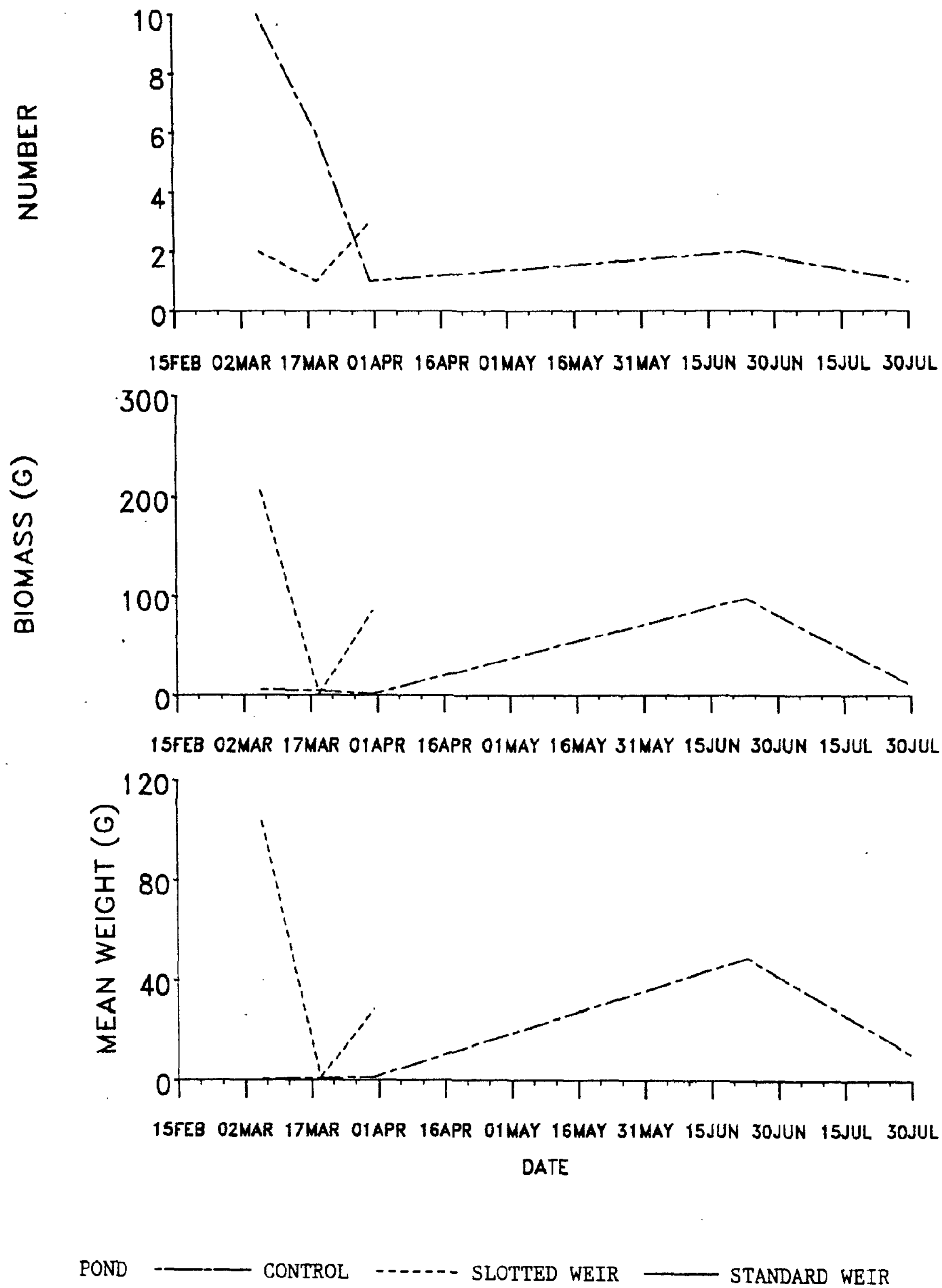


POND ——— CONTROL ------ SLOTTED WEIR ——— STANDARD WEIR

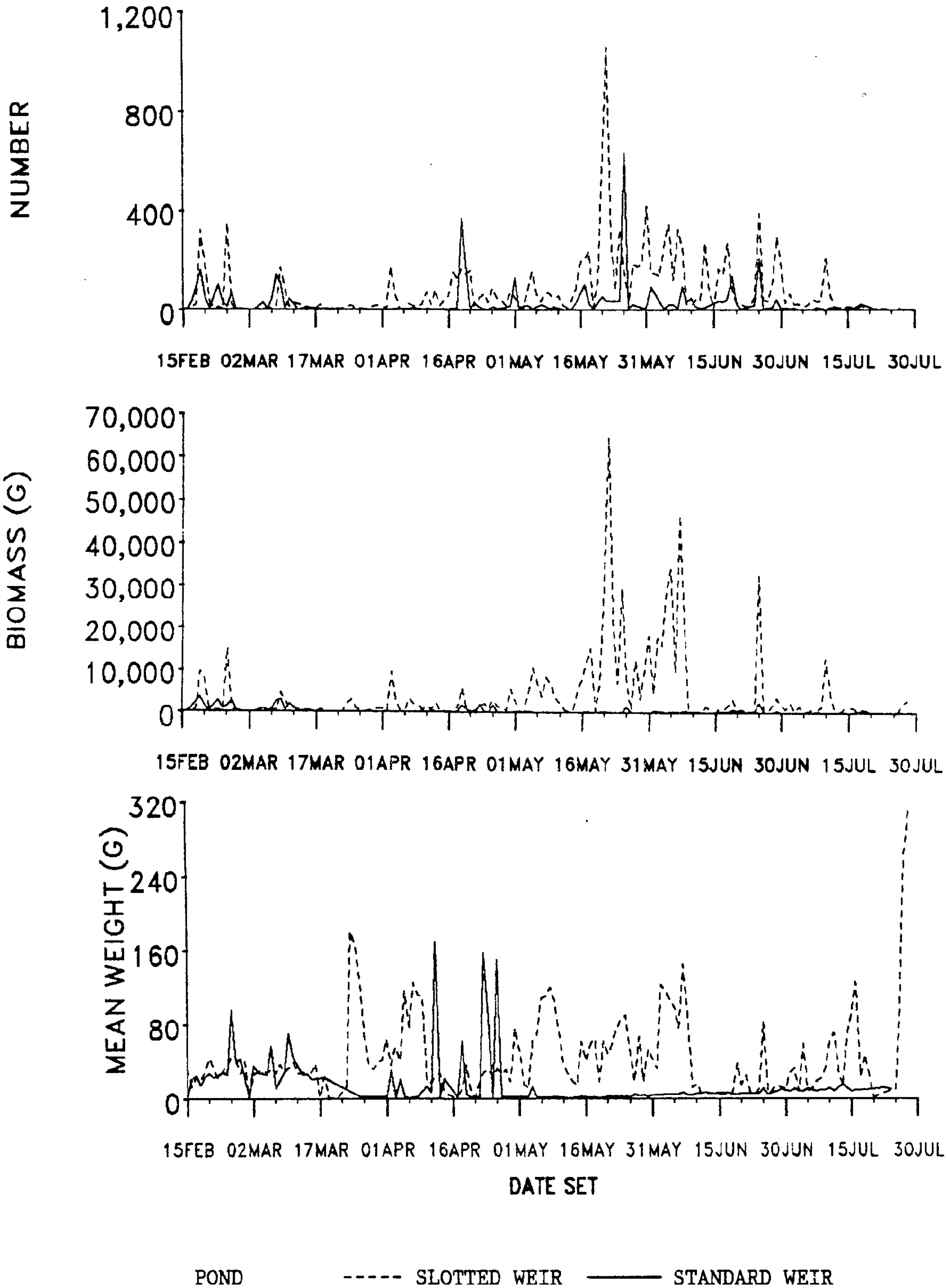
Appendix Figure 6. Number, biomass, and mean weight of spot taken by trawls in each pond.



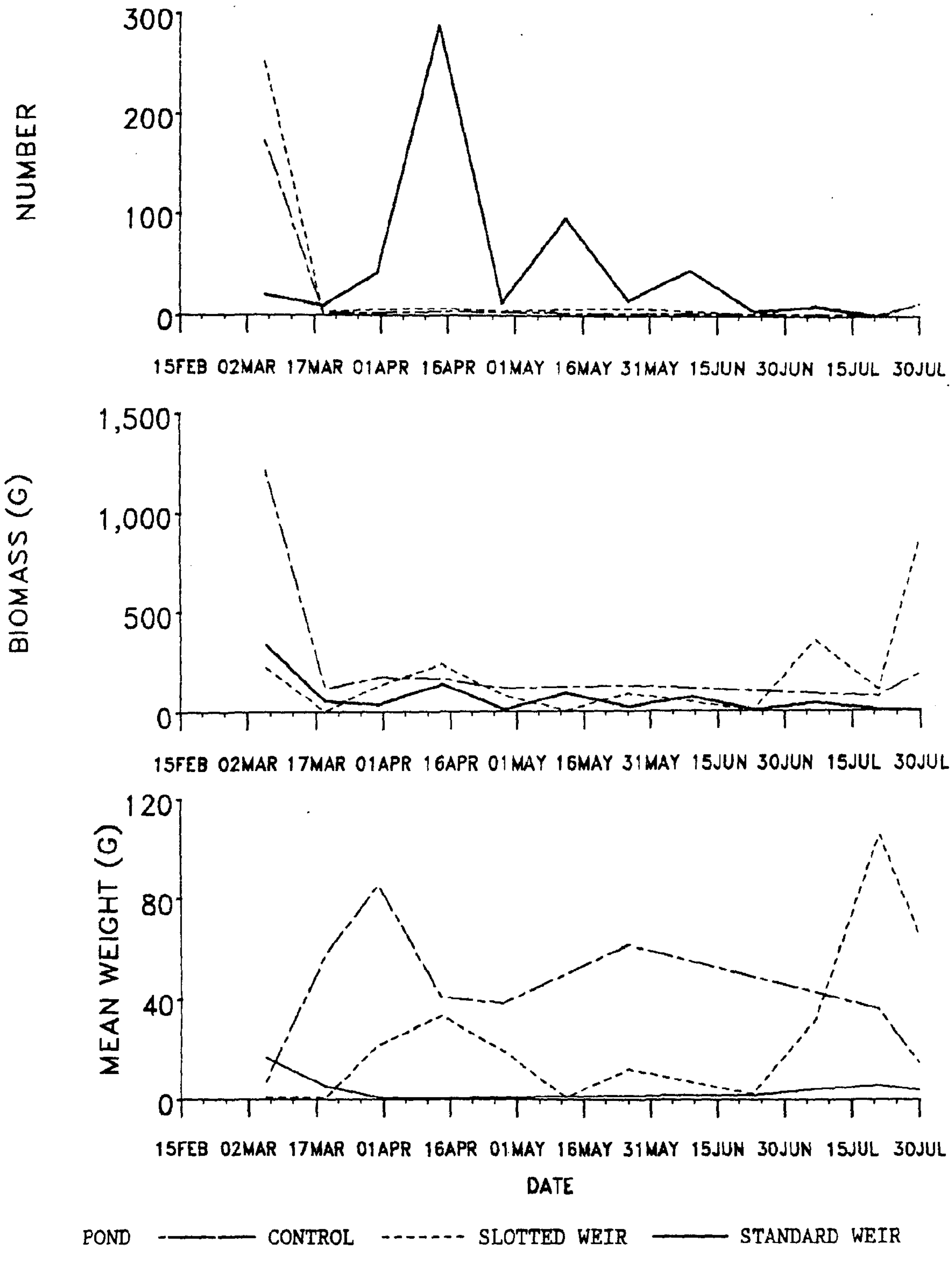
Appendix Figure 7. Number, biomass, and mean weight of southern flounder taken by the traps in each experimental pond.



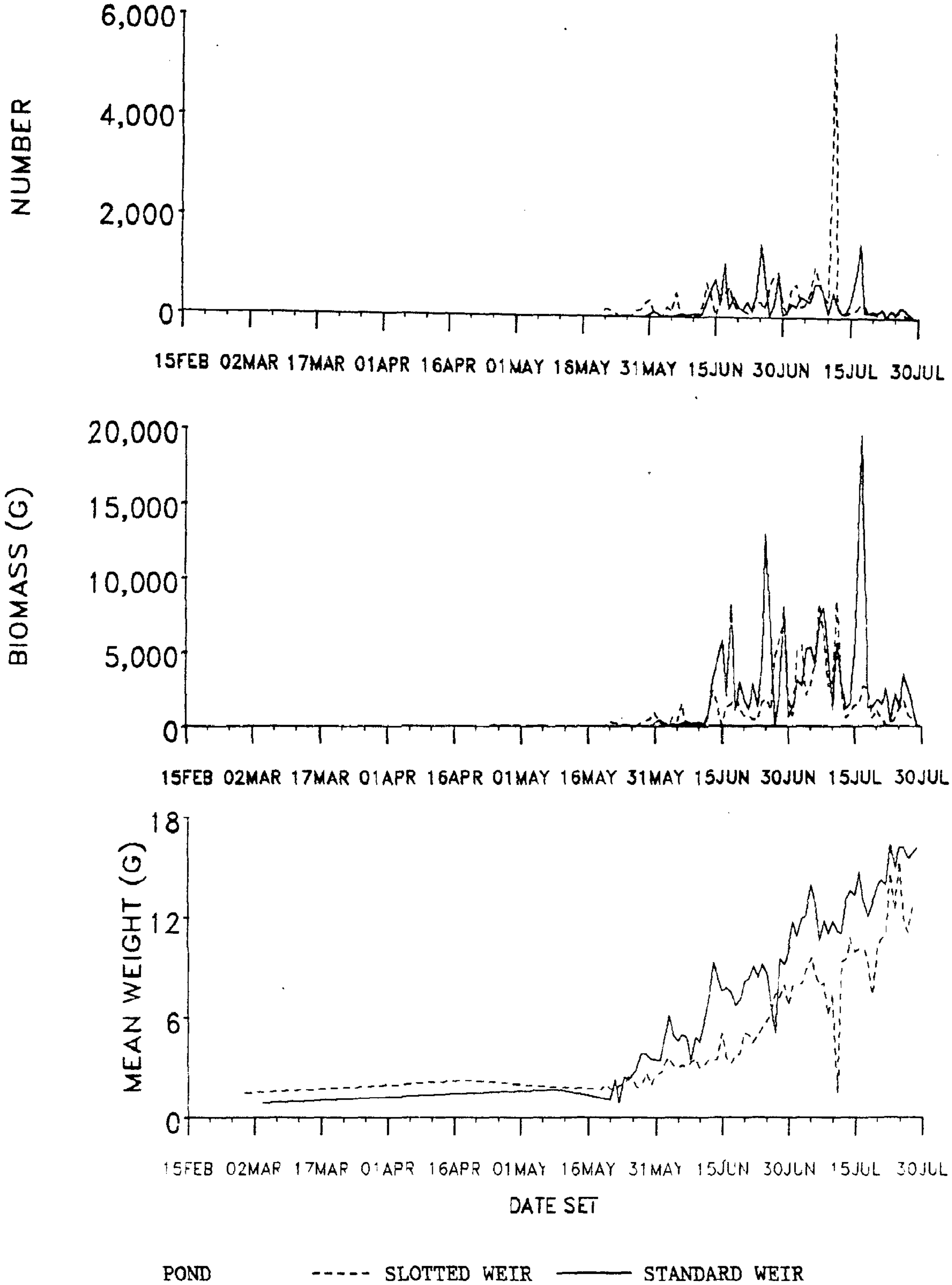
Appendix Figure 8. Number, biomass, and mean weight of southern flounder taken by trawls in each pond.



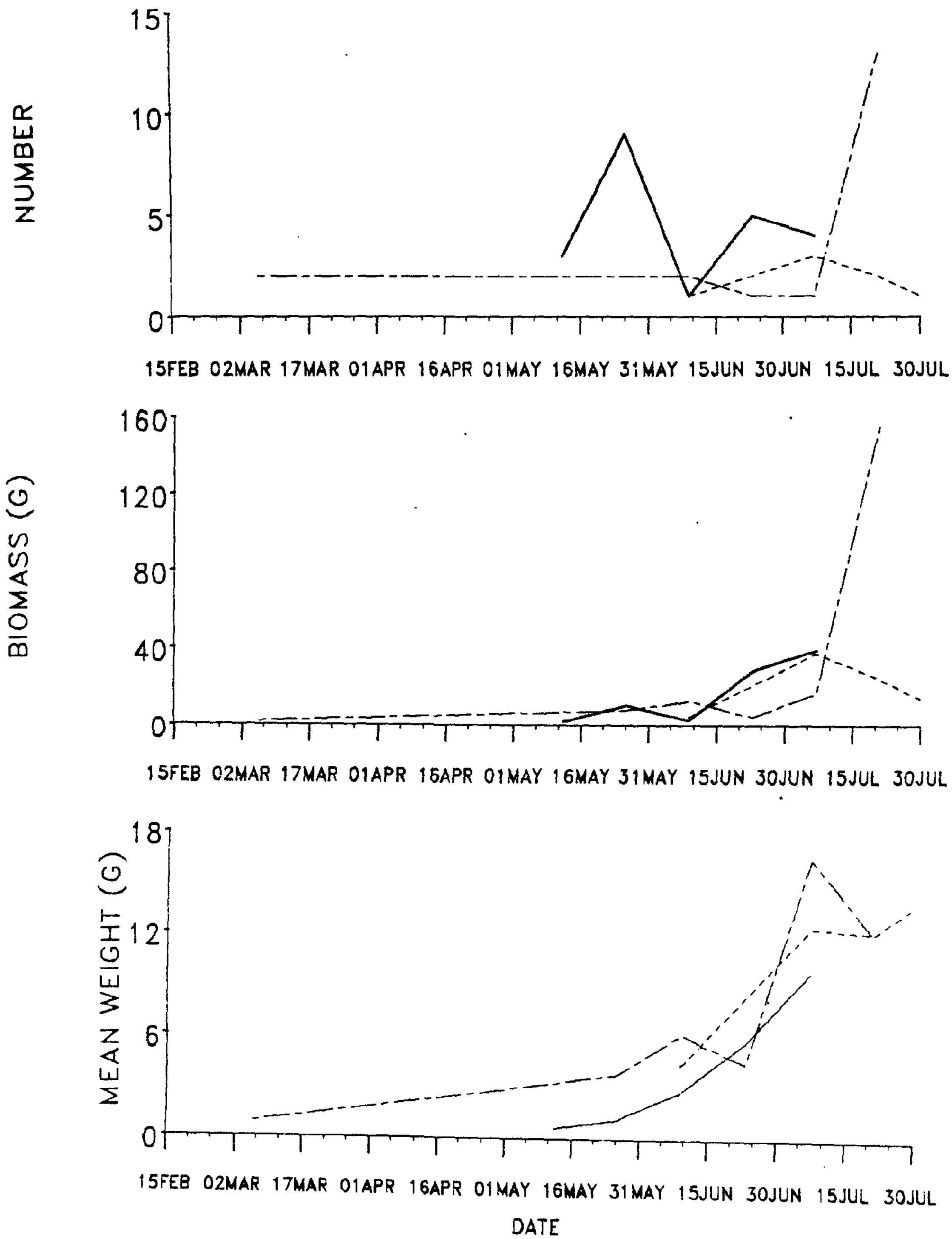
Appendix Figure 9. Number, biomass, and mean weight of striped mullet taken by the traps in each experimental pond.



Appendix Figure 10. Number, biomass, and mean weight of striped mullet taken by trawls in each pond.

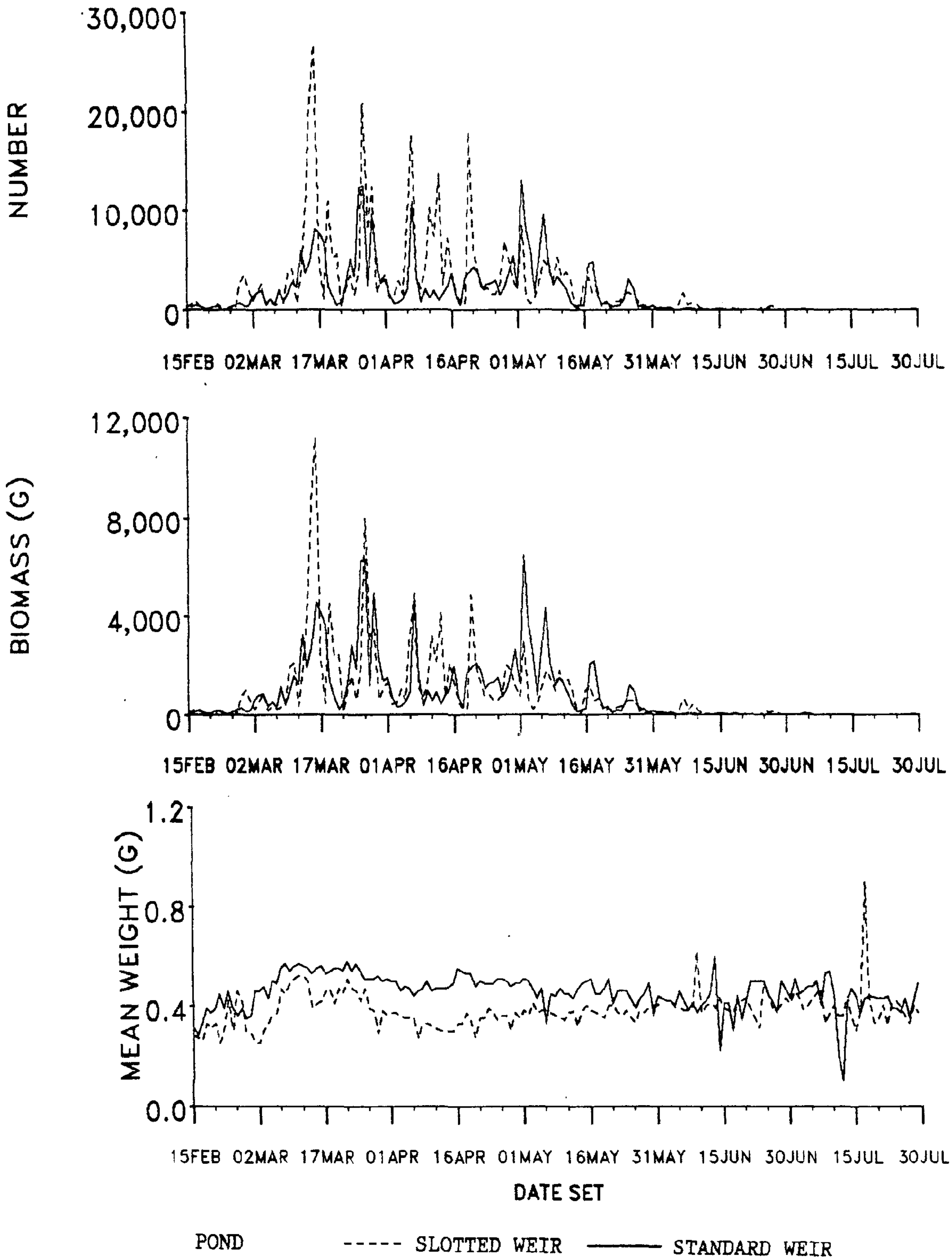


Appendix Figure 11. Number, biomass, and mean weight of white mullet taken by the traps in each experimental pond.

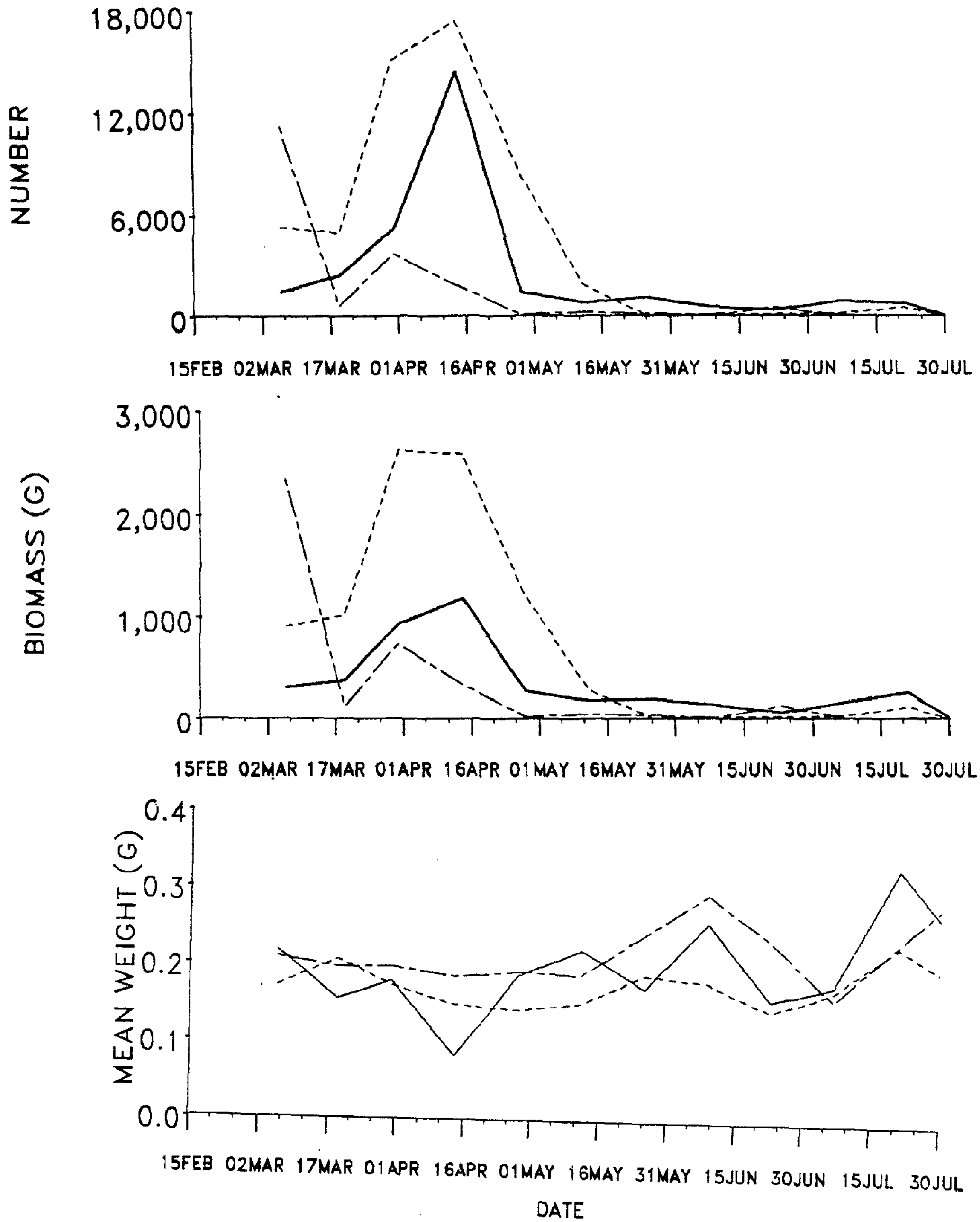


POND ——— CONTROL ------- SLOTTED WEIR ——— STANDARD WEIR

Appendix Figure 12. Number, biomass, and mean weight of white mullet taken by trawls in each pond.

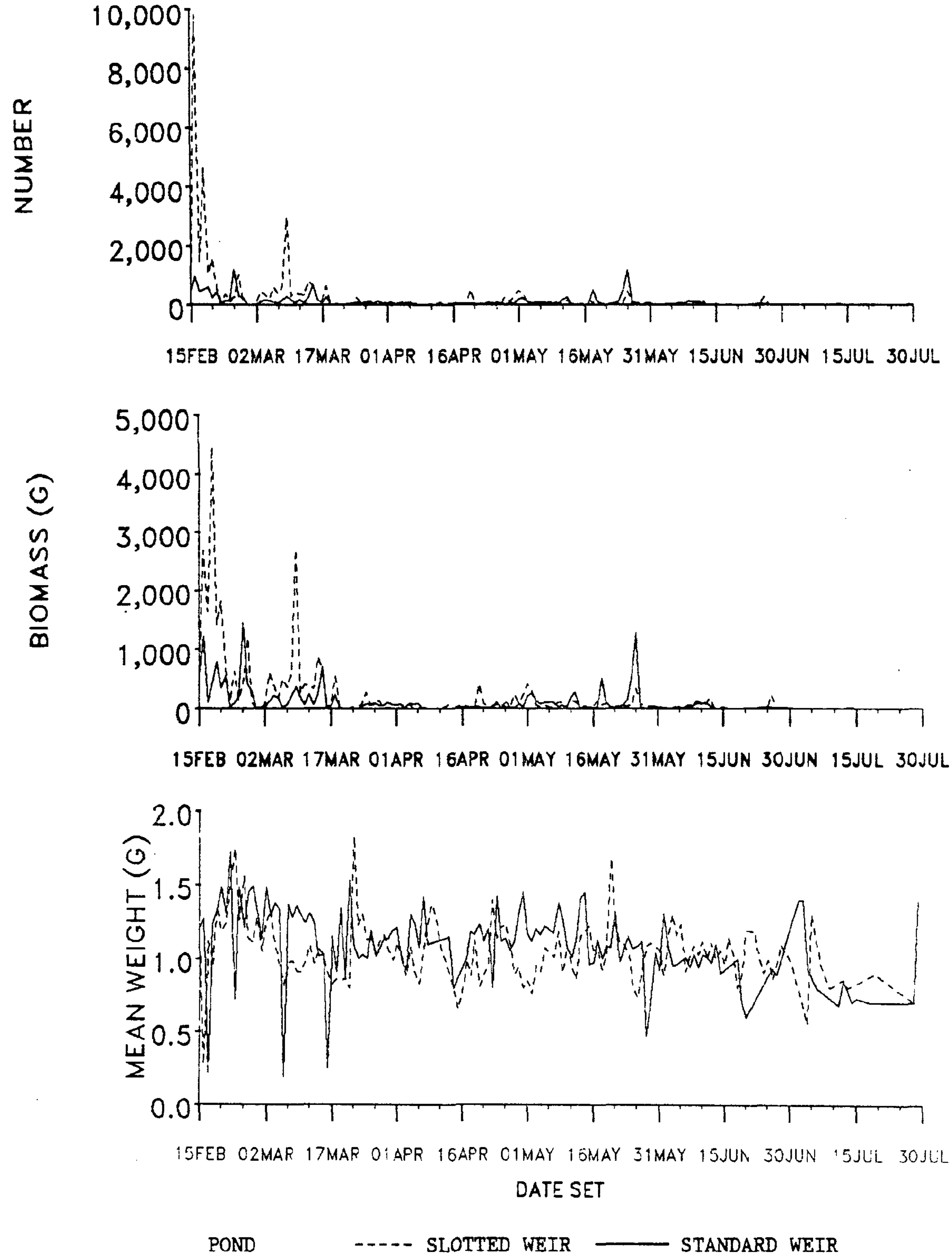


Appendix Figure 13. Number, biomass, and mean weight of grass shrimp taken by the traps in each experimental pond.

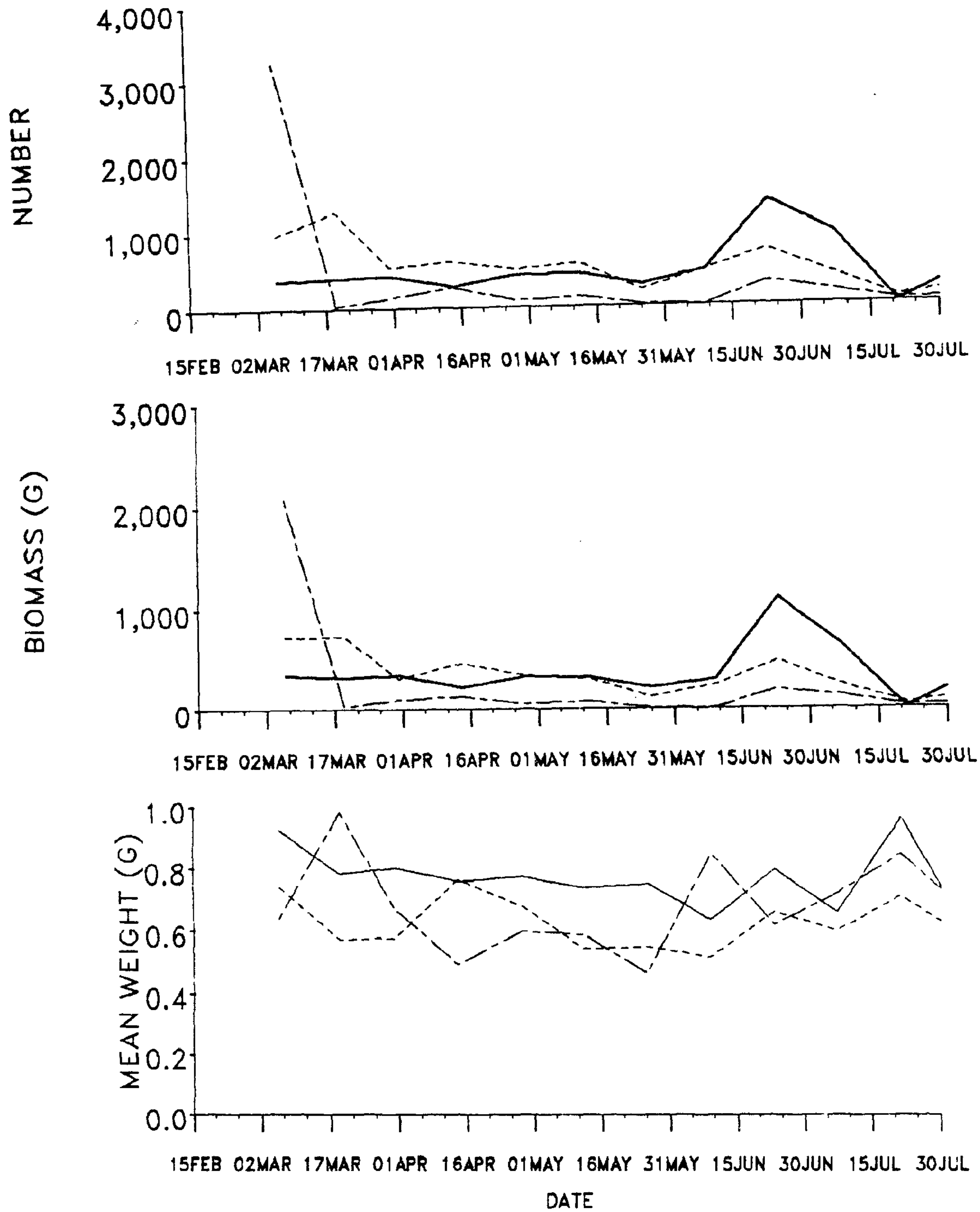


POND ——— CONTROL ------- SLOTTED WEIR ——— STANDARD WEIR

Appendix Figure 14. Number, biomass, and mean weight of grass shrimp taken by trawls in each pond.

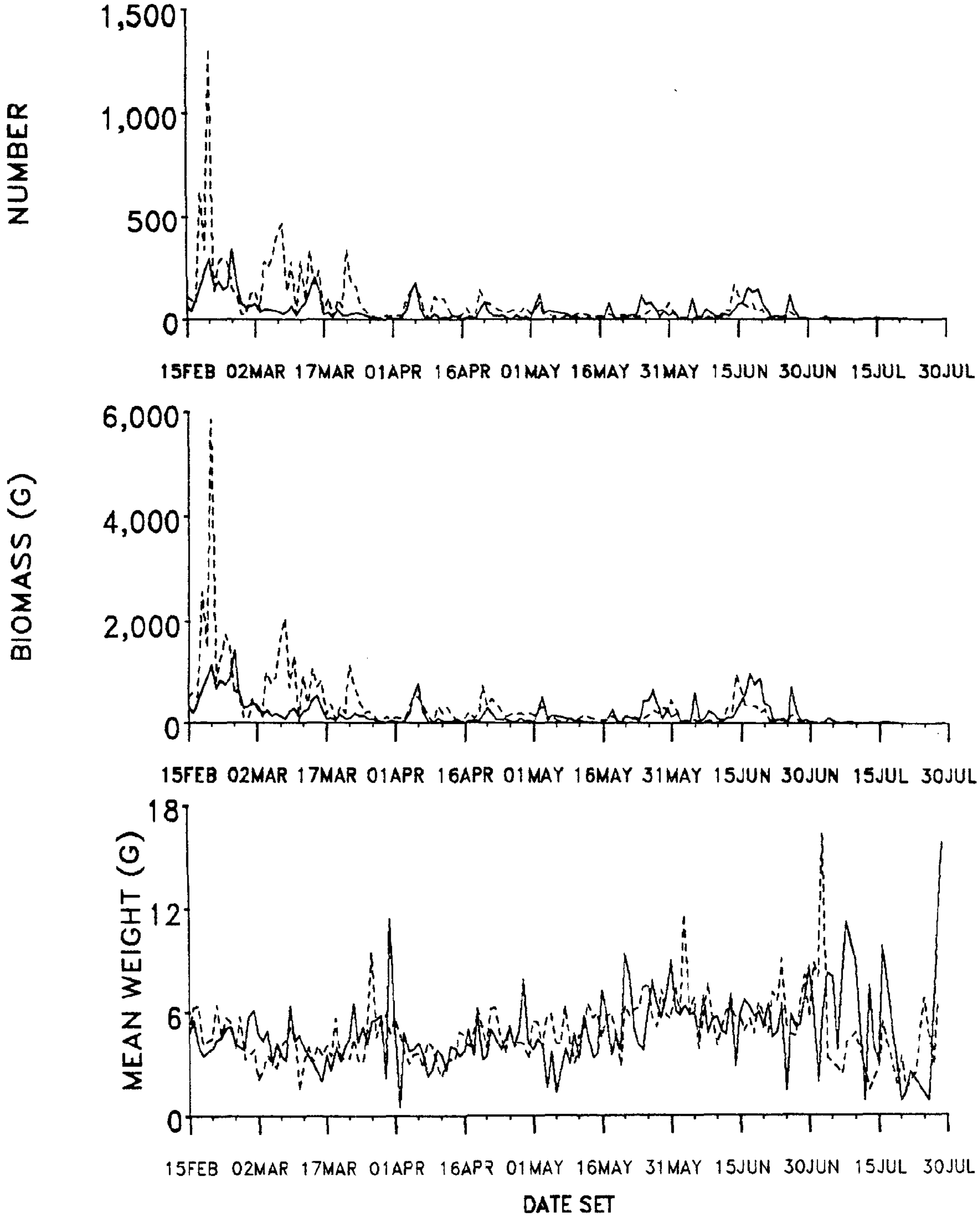


Appendix Figure 15. Number, biomass, and mean weight of inland silverside taken by the traps in each experimental pond.



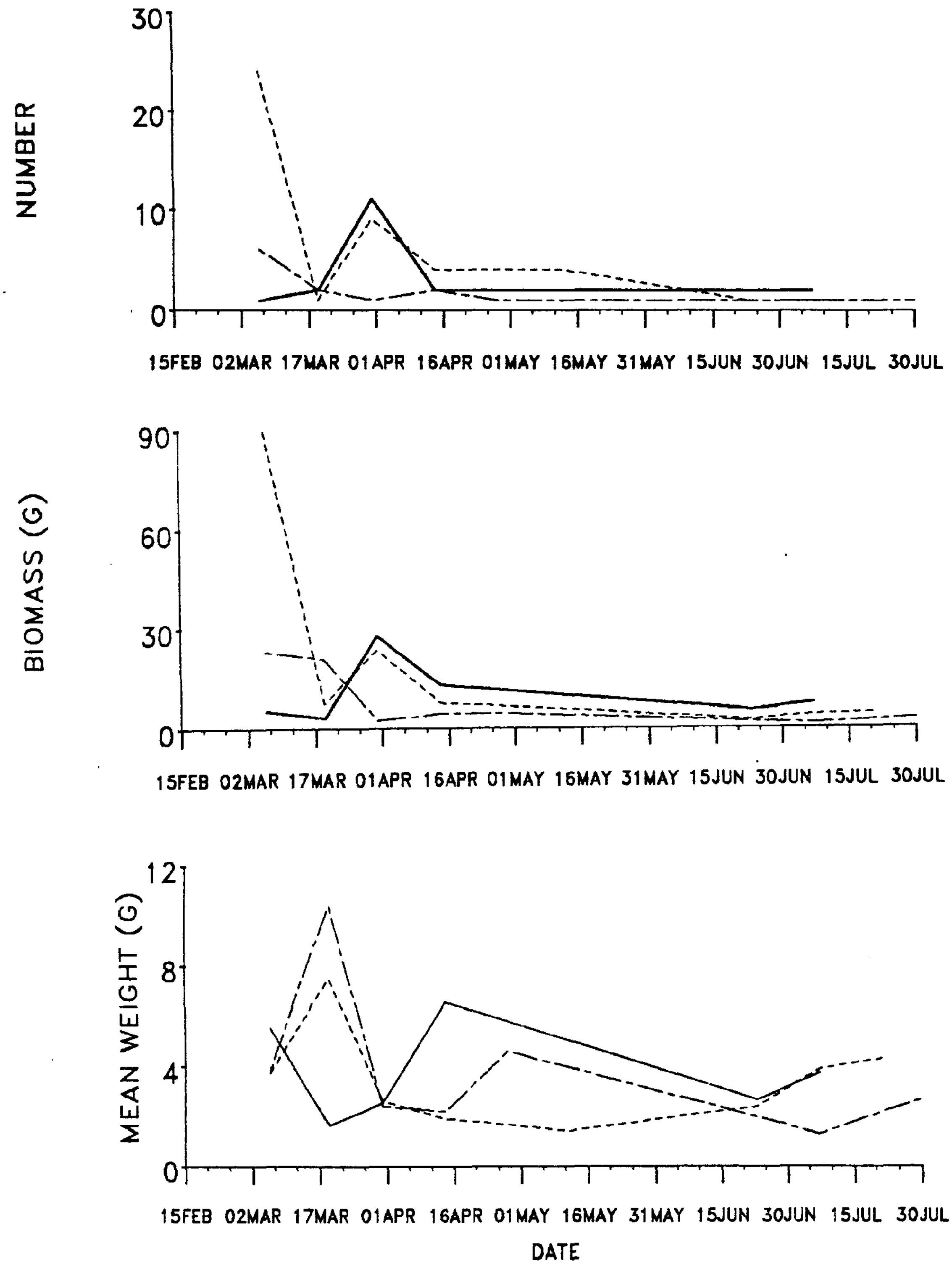
POND ——-—— CONTROL ------ SLOTTED WEIR ——— STANDARD WEIR

Appendix Figure 16. Number, biomass, and mean weight of inland silverside taken by trawls in each pond.



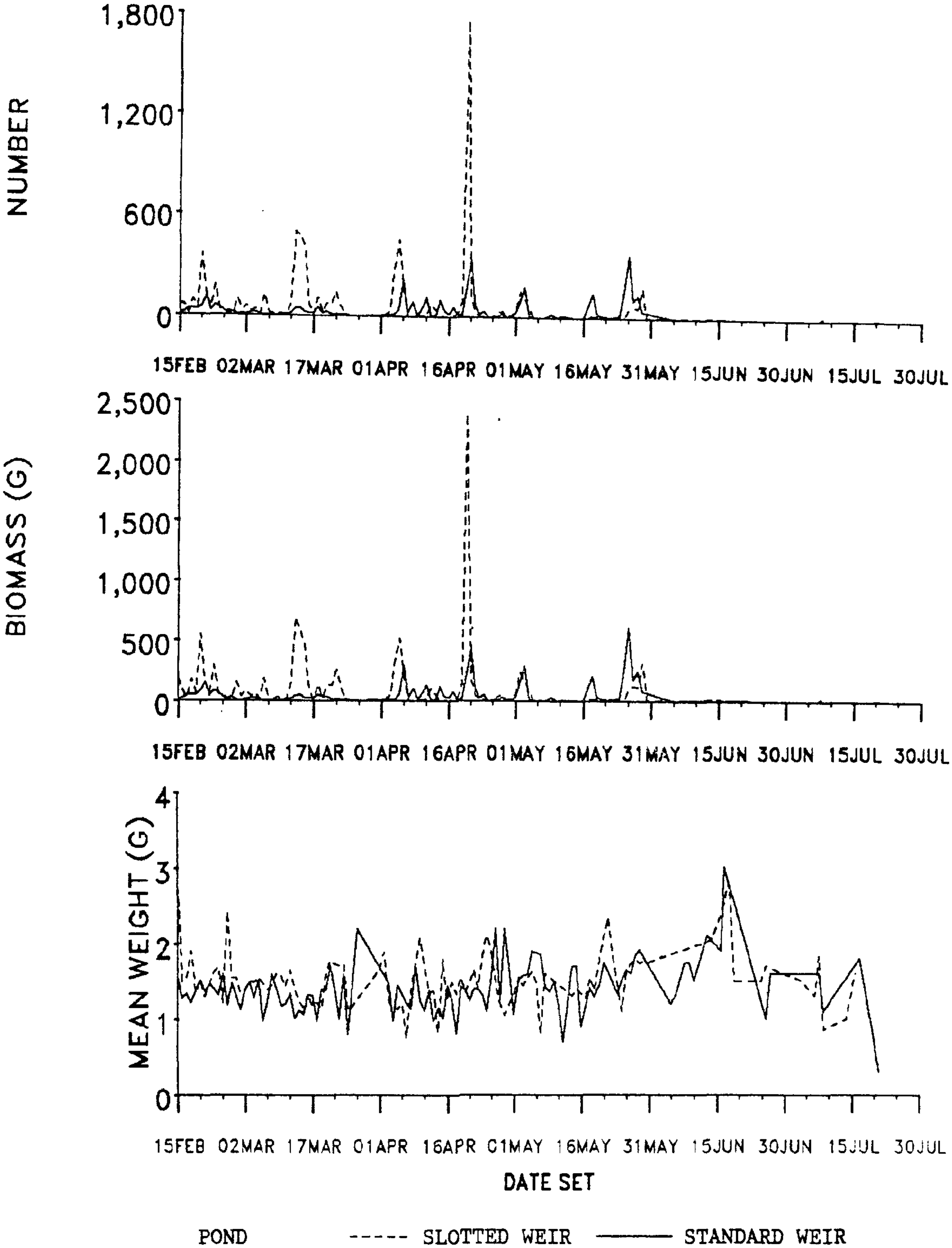
POND ----- SLOTTED WEIR ——— STANDARD WEIR

Appendix Figure 17. Number, biomass, and mean weight of gulf killifish taken by the traps in each experimental pond.

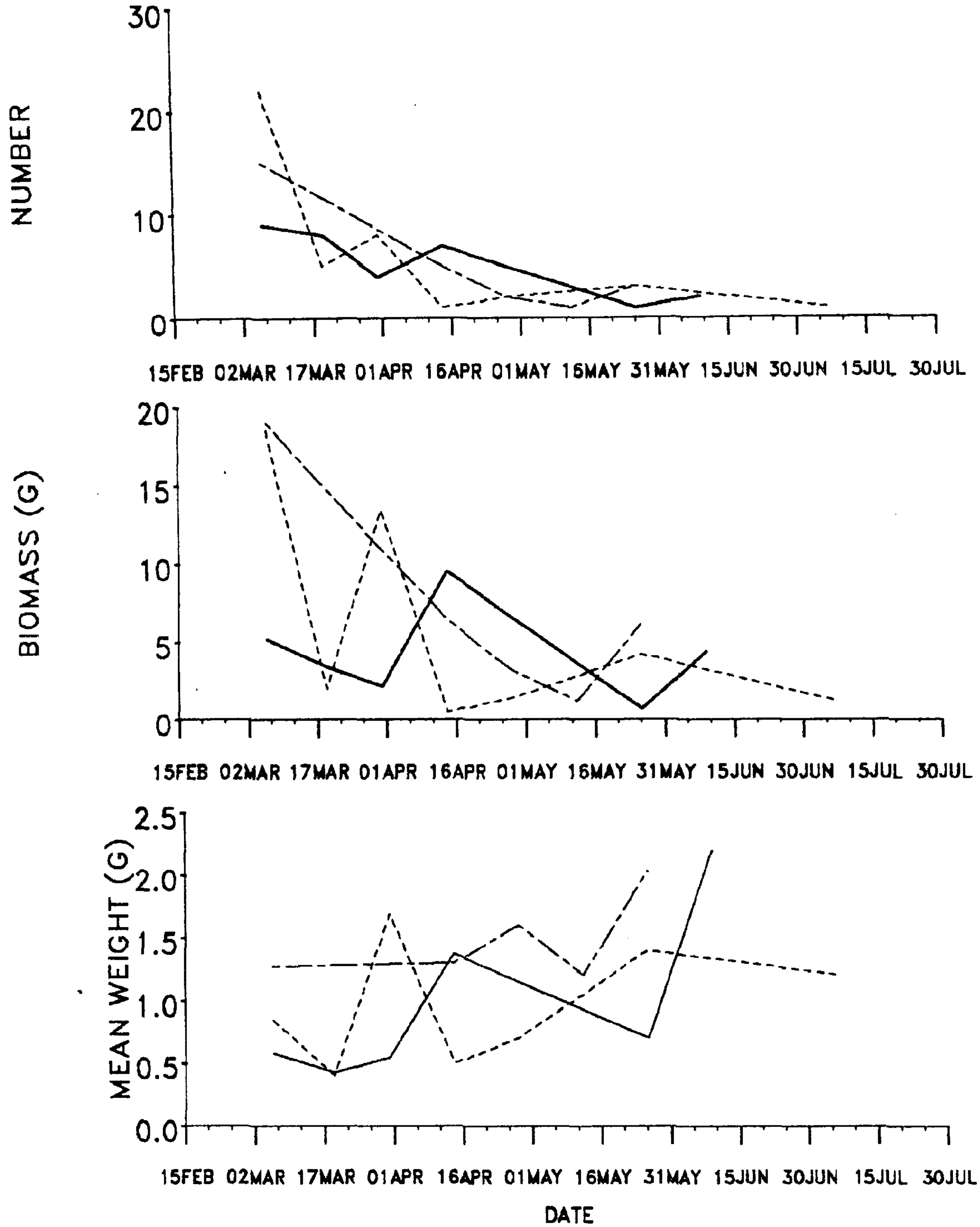


POND ———— CONTROL ------- SLOTTED WEIR ——— STANDARD WEIR

Appendix Figure 18. Number, biomass, and mean weight of gulf killifish taken by trawls in each pond.

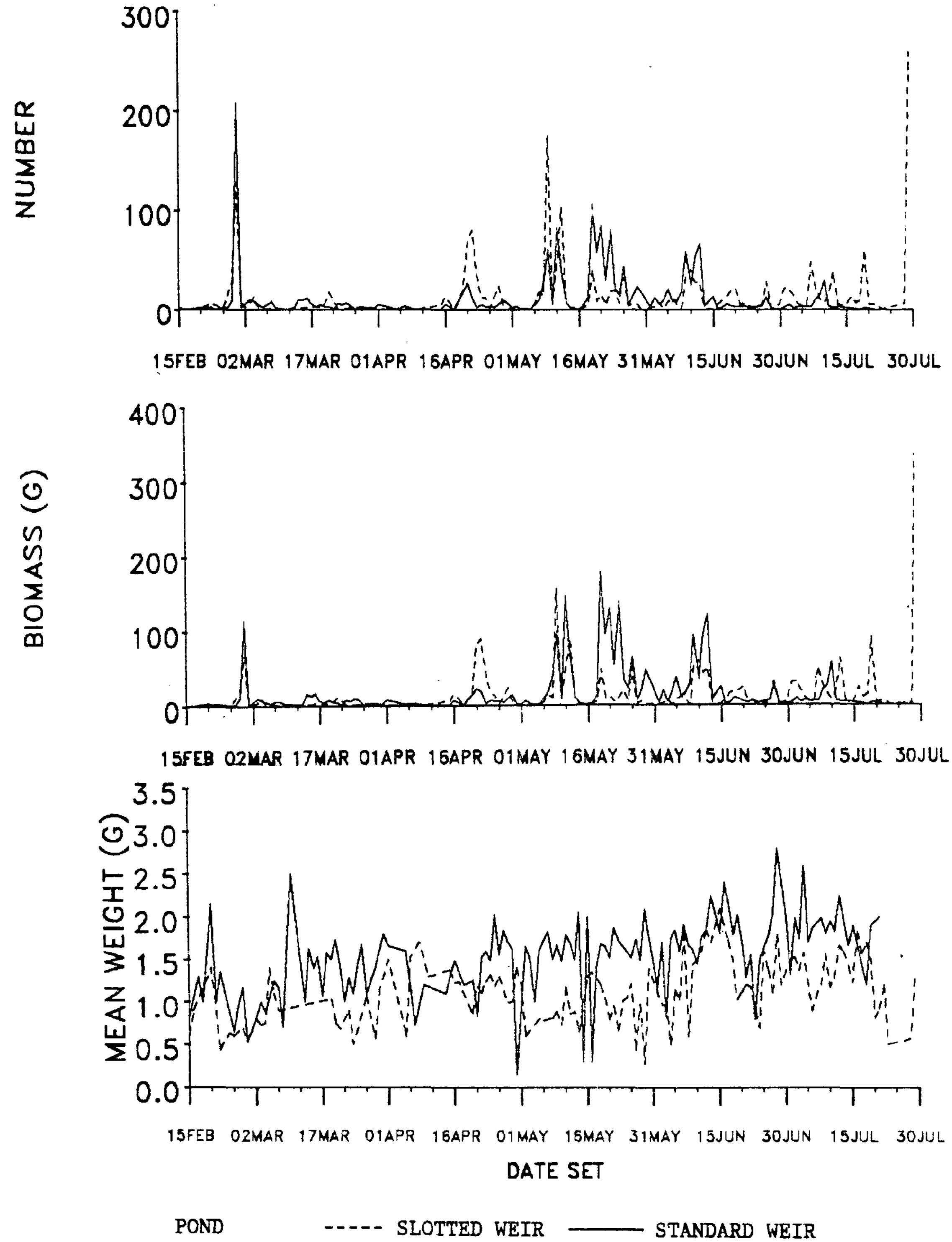


Appendix Figure 19. Number, biomass, and mean weight of sheepshead minnow taken by the traps in each experimental pond.

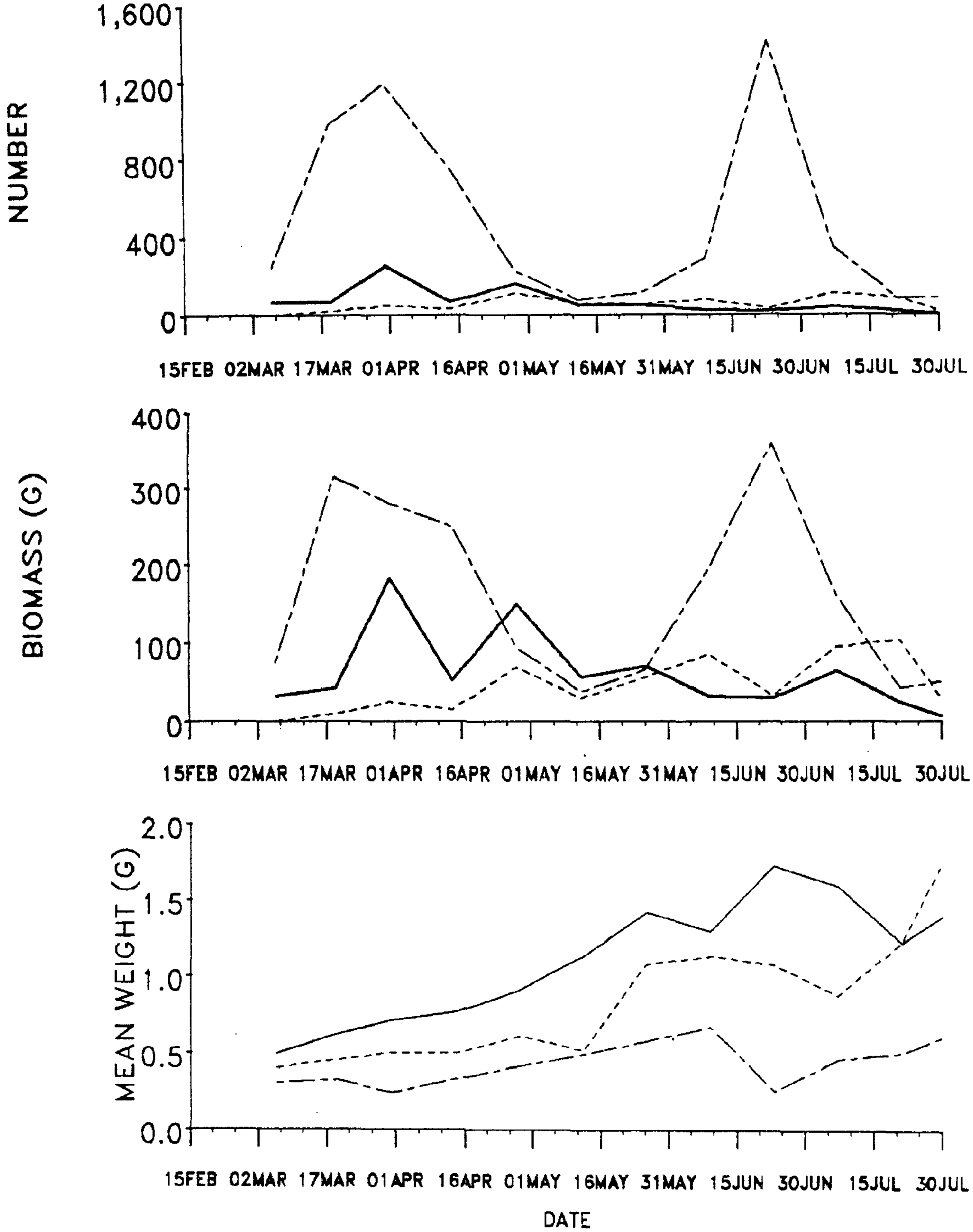


POND ——— CONTROL ------ SLOTTED WEIR ——— STANDARD WEIR

Appendix Figure 20. Number, biomass, and mean weight of sheepshead minnow taken by trawls in each pond.

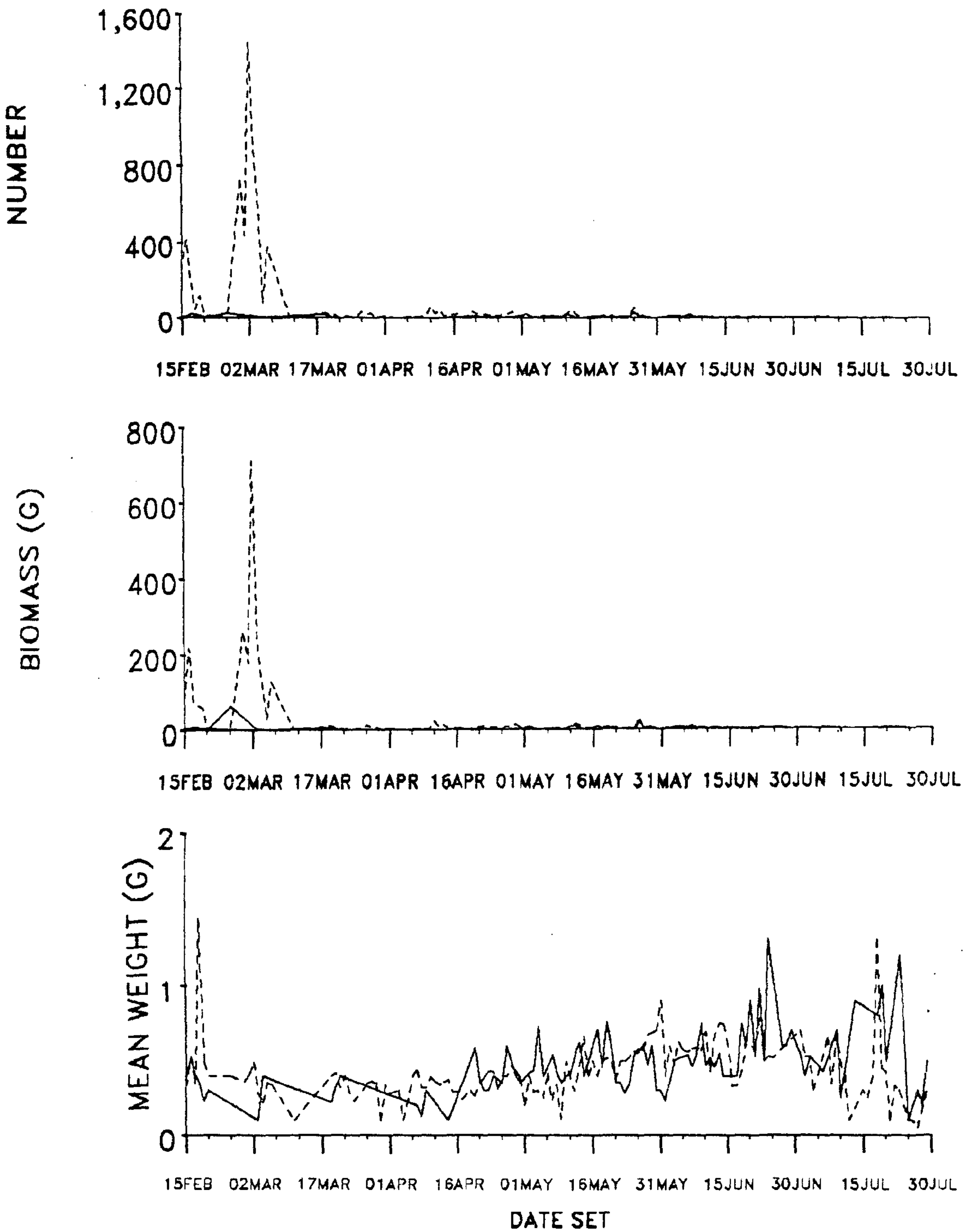


Appendix Figure 21. Number, biomass, and mean weight of bay anchovy taken by the traps in each experimental pond.



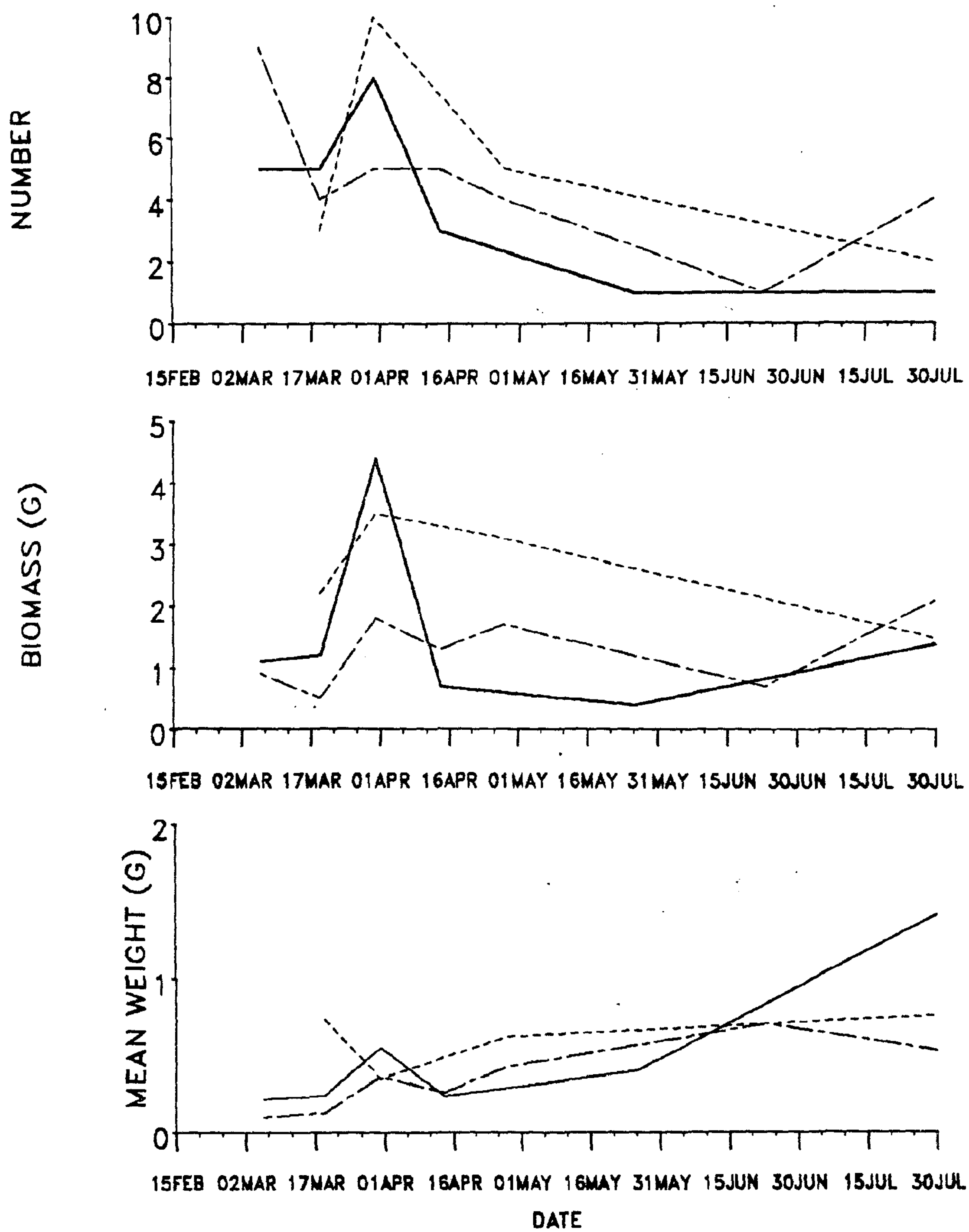
POND ——— CONTROL ------- SLOTTED WEIR ——— STANDARD WEIR

Appendix Figure 22. Number, biomass, and mean weight of bay anchovy taken by trawls in each pond.



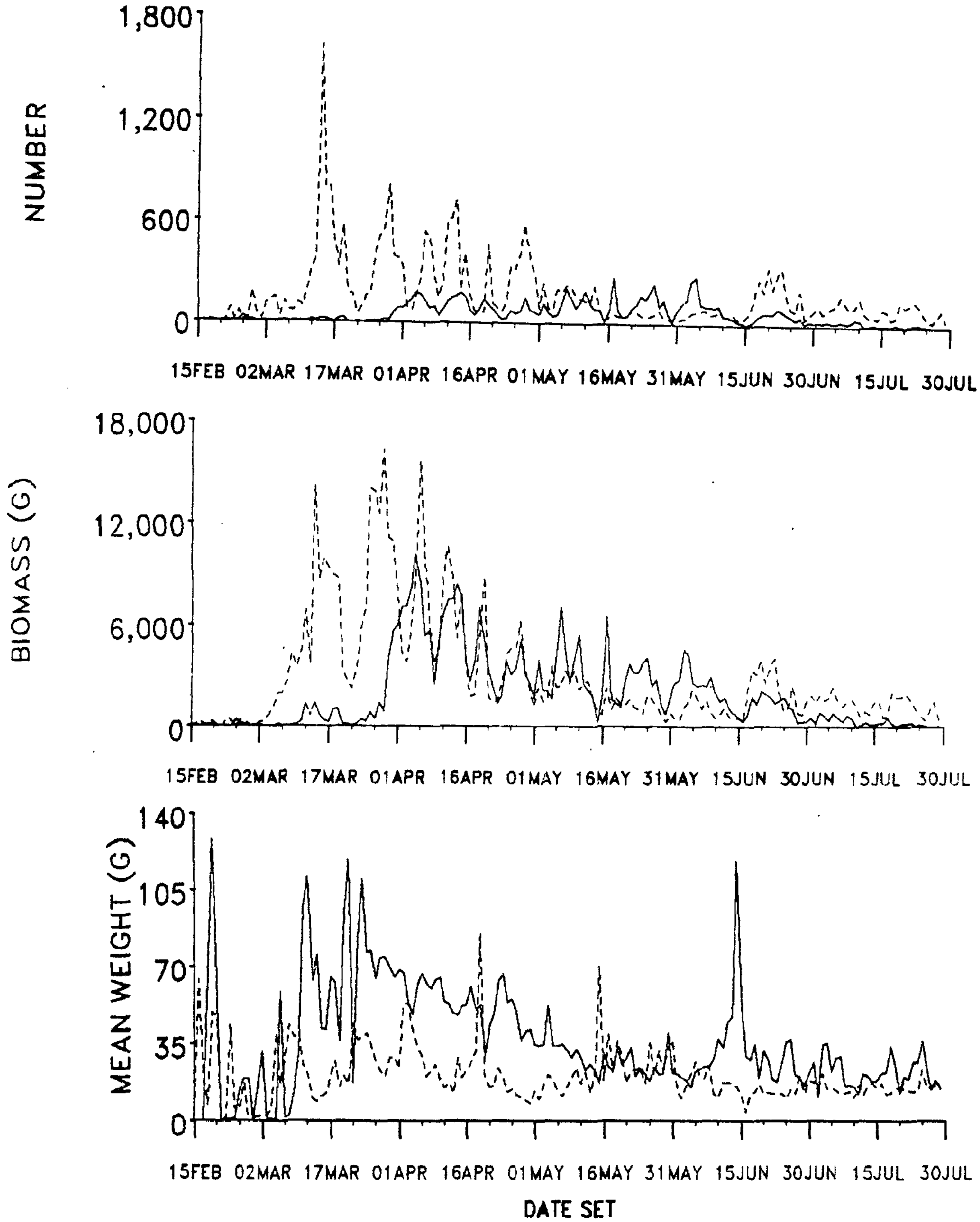
POND ----- SLOTTED WEIR ——— STANDARD WEIR

Appendix Figure 23. Number, biomass, and mean weight of blue crab (<25mm) taken by the traps in each experimental pond.



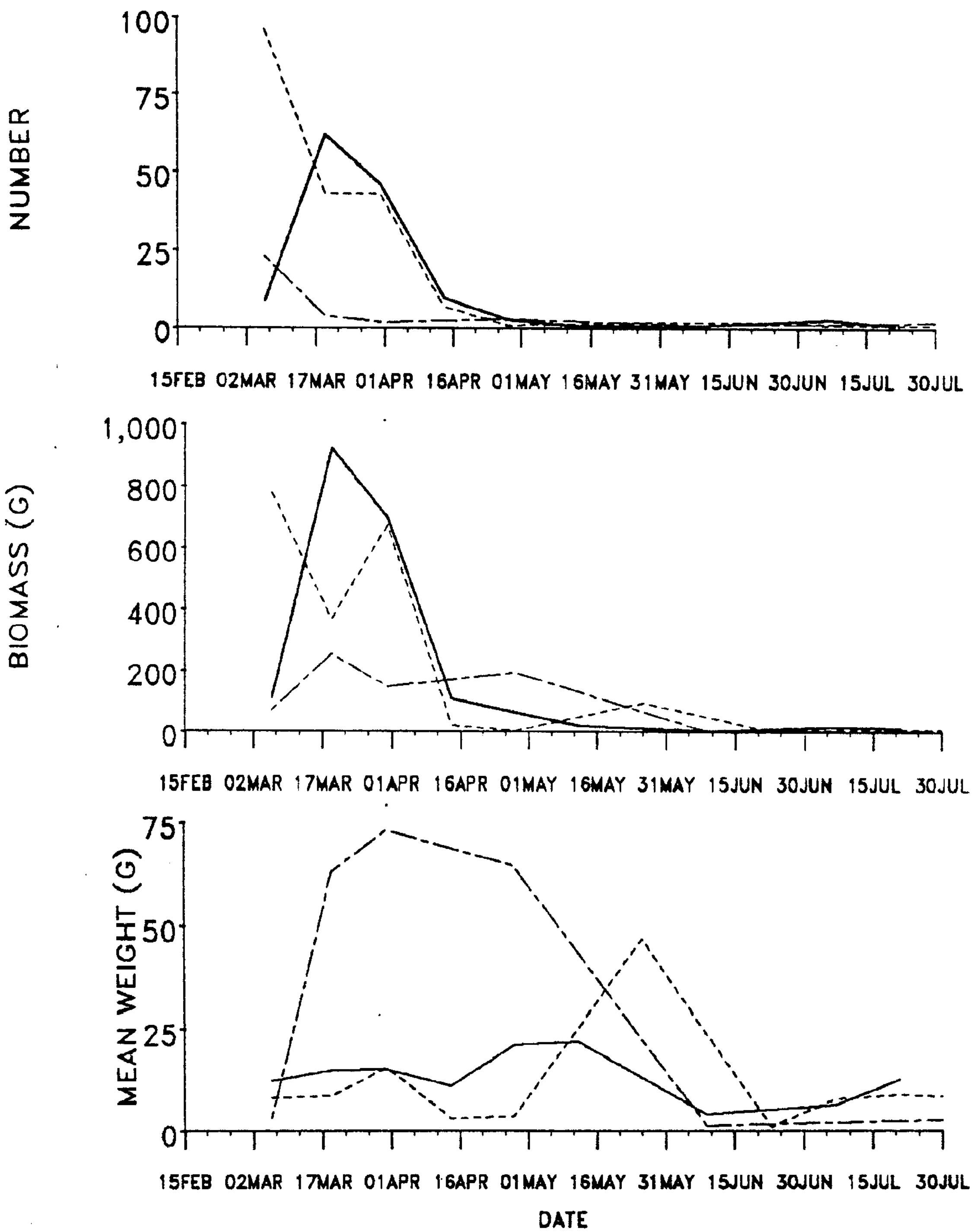
POND ——— CONTROL ------- SLOTTED WEIR ——— STANDARD WEIR

Appendix Figure 24. Number, biomass, and mean weight of blue crab (< 25 mm) taken by trawls in each pond.



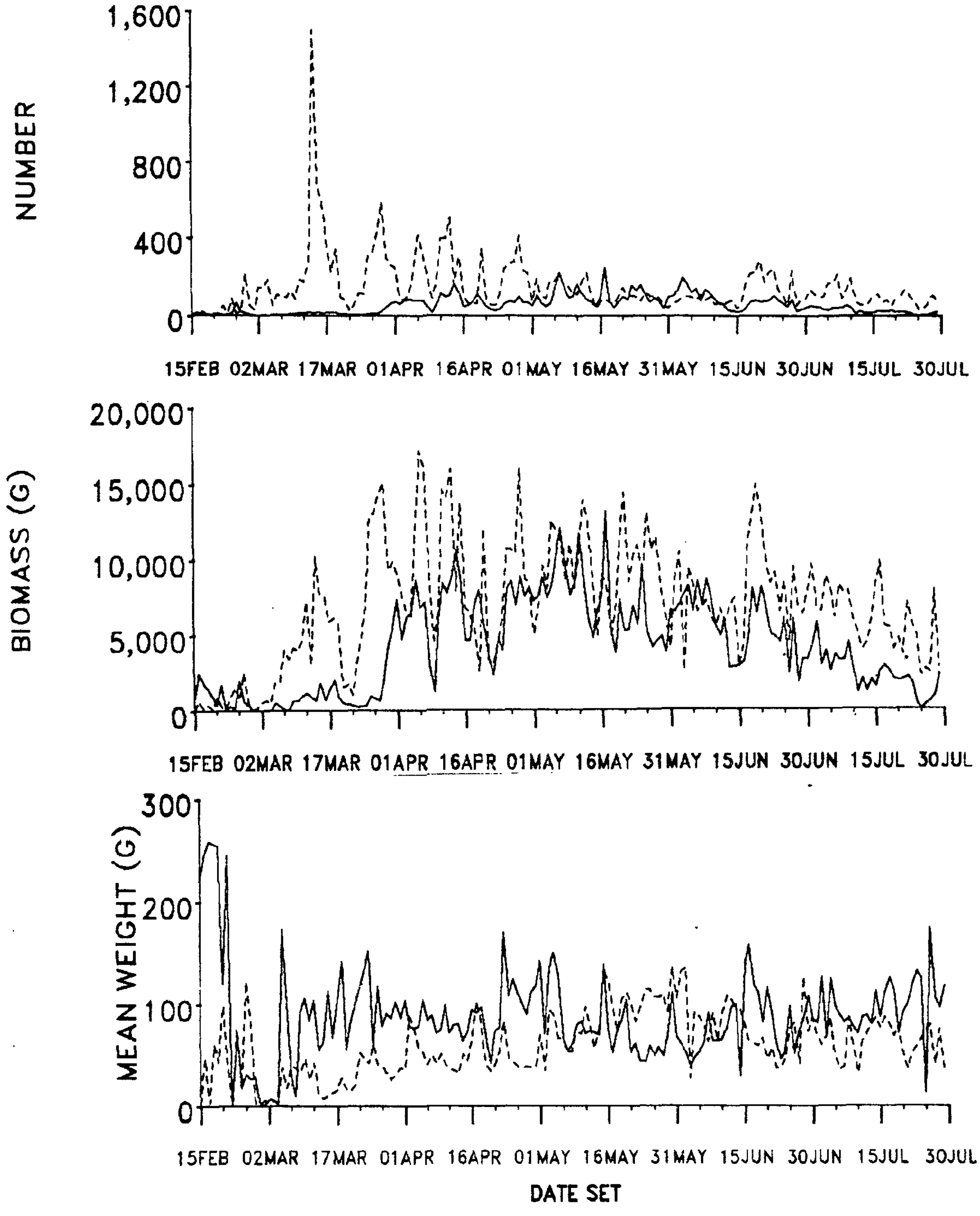
POND ----- SLOTTED WEIR ——— STANDARD WEIR

Appendix Figure 25. Number, biomass, and mean weight of immature female crab taken by the traps in each experimental pond.



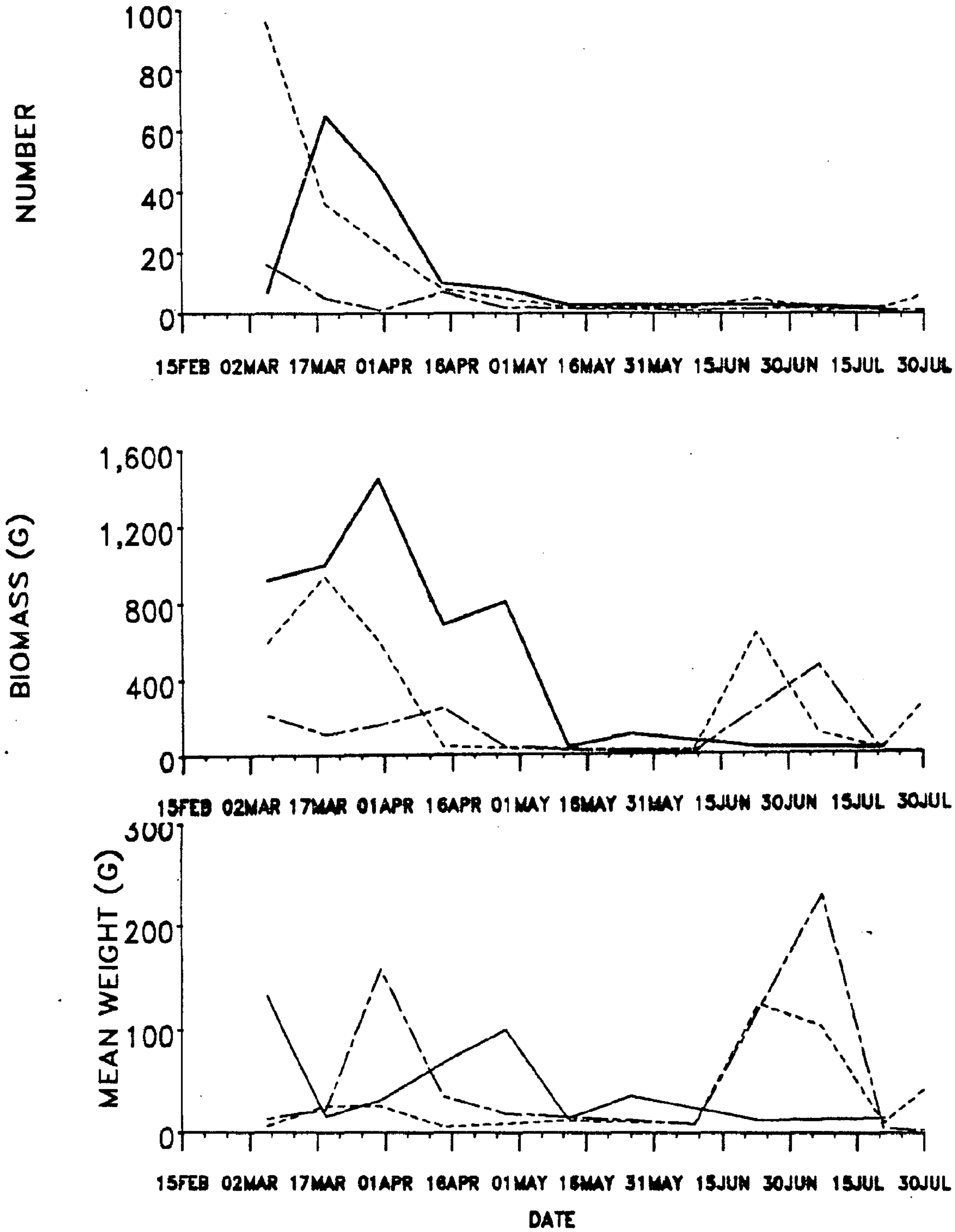
POND ——— CONTROL ------ SLOTTED WEIR ——— STANDARD WEIR

Appendix Figure 26. Number, biomass, and mean weight of immature female crab taken by trawls in each pond.



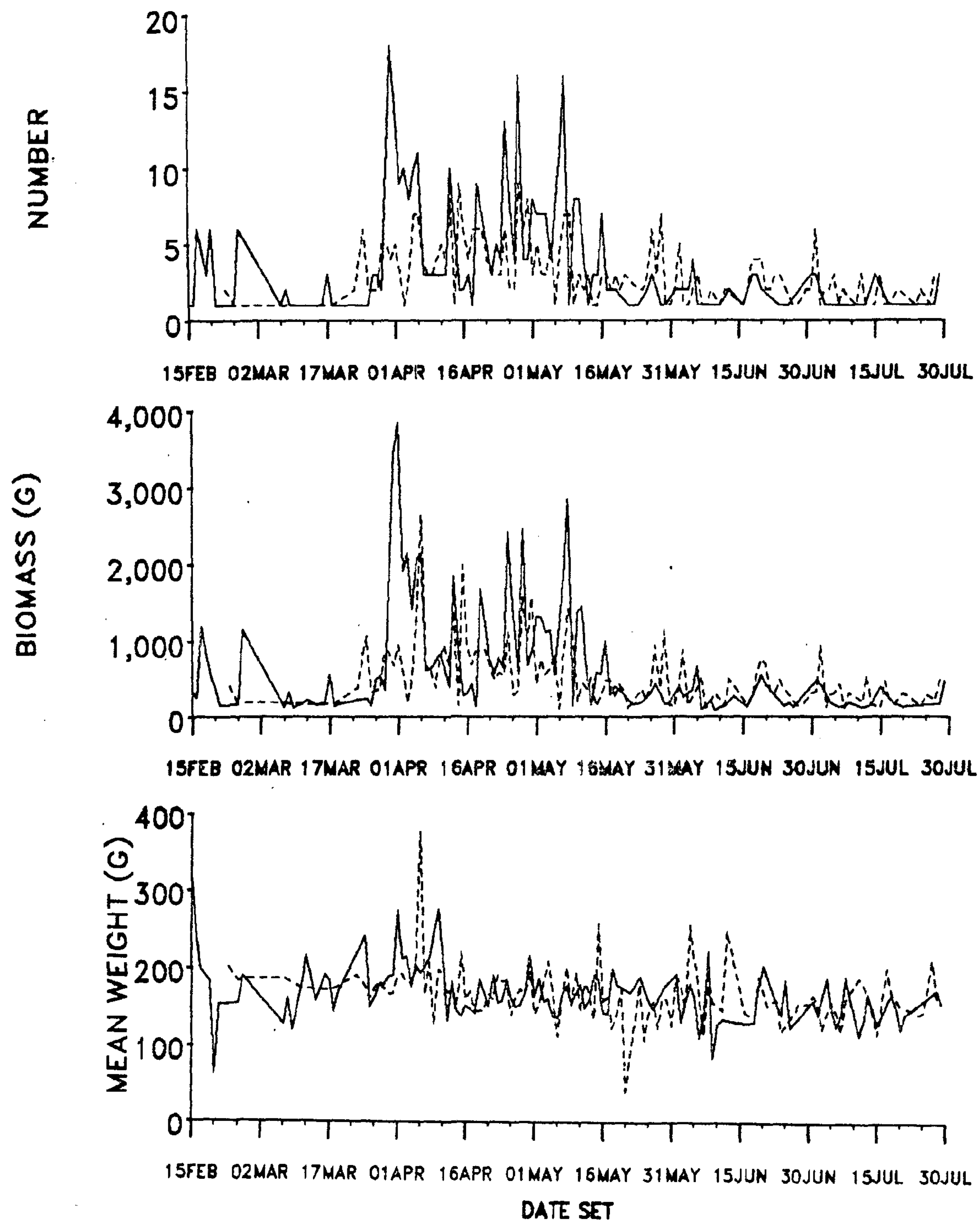
POND ----- SLOTTED WEIR ——— STANDARD WEIR

Appendix Figure 27. Number, biomass, and mean weight of male blue crab taken by the traps in each experimental pond.



POND ——— CONTROL ------- SLOTTED WEIR ——— STANDARD WEIR

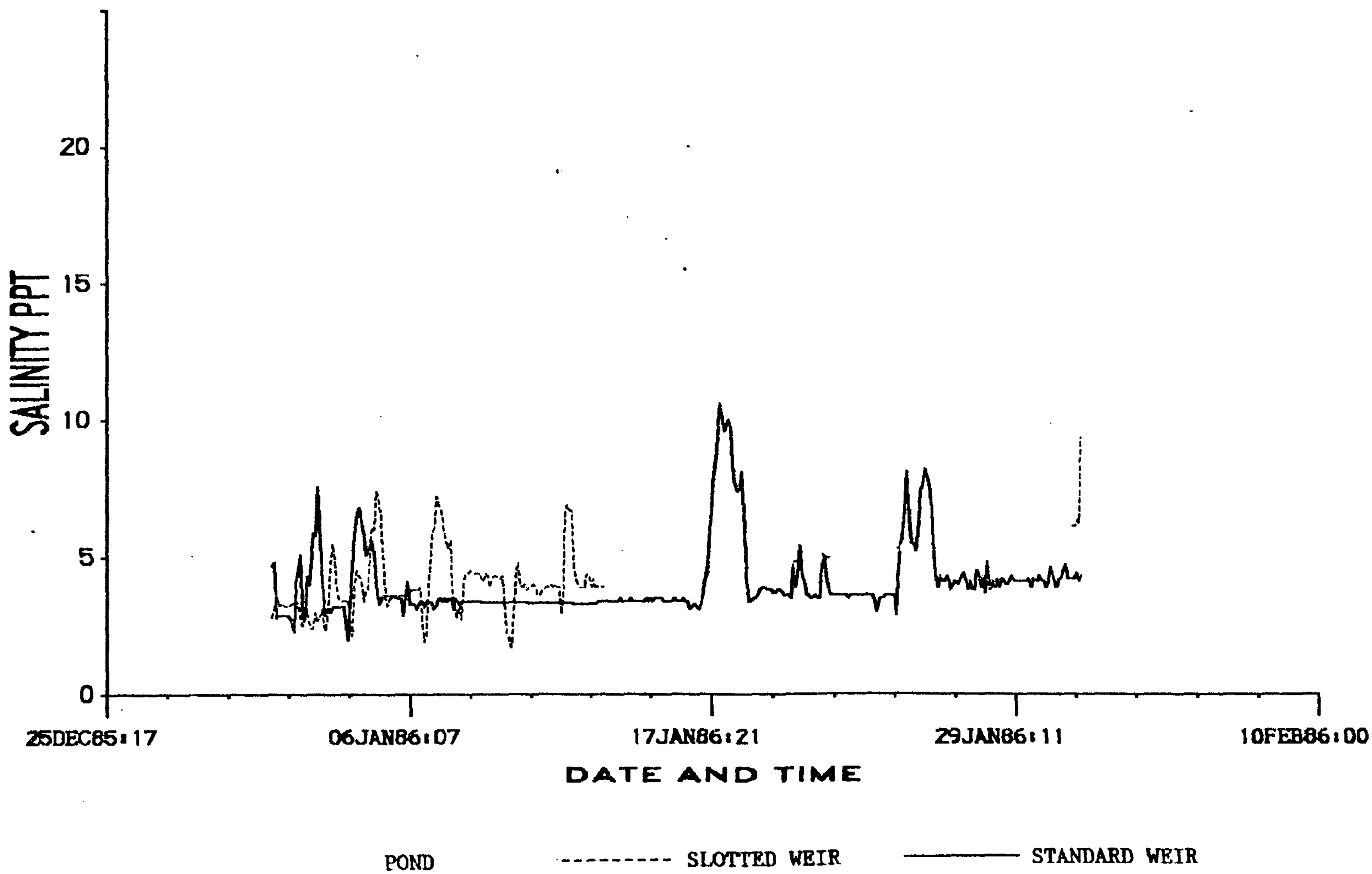
Appendix Figure 28. Number, biomass, and mean weight of male blue crab taken by trawls in each pond.



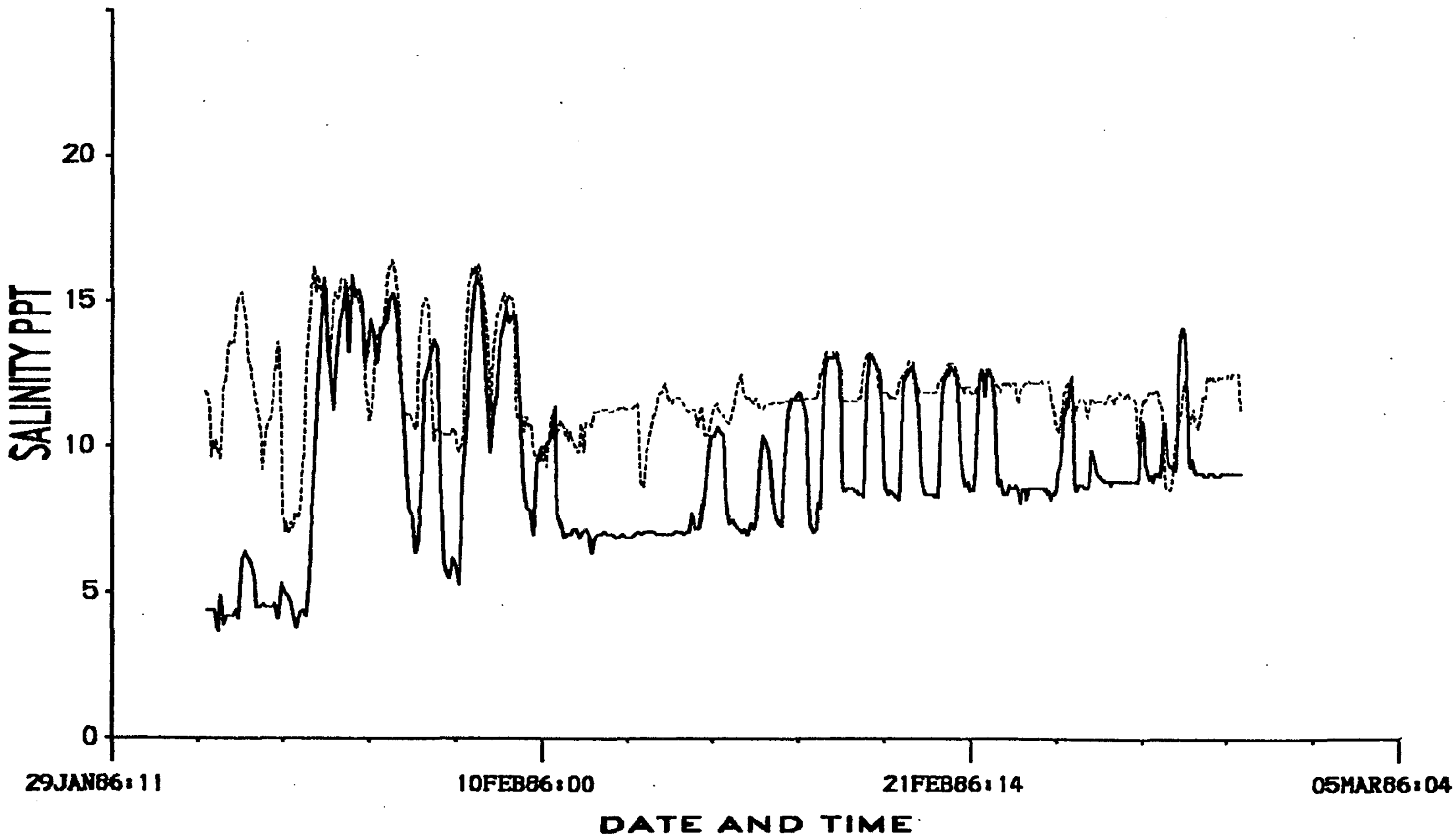
POND ----- SLOTTED WEIR ——— STANDARD WEIR

Appendix Figure 29. Number, biomass, and mean weight of mature female crab taken by the traps in each experimental pond.

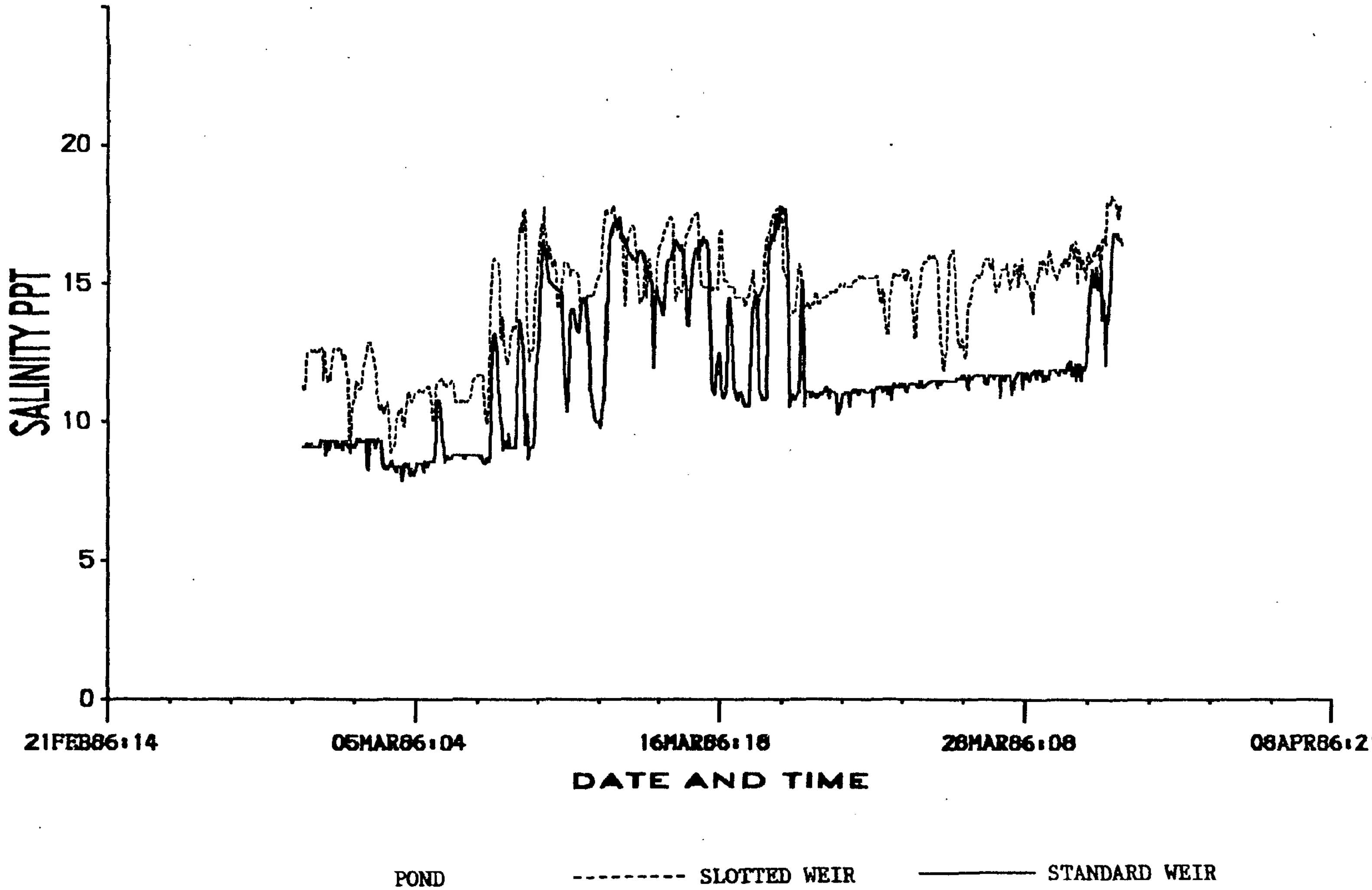
Appendix Figure 30. Hourly salinity for both experimental ponds taken at the environmental stations by the Hydrolabs, from 17 January through 30 July 1986.



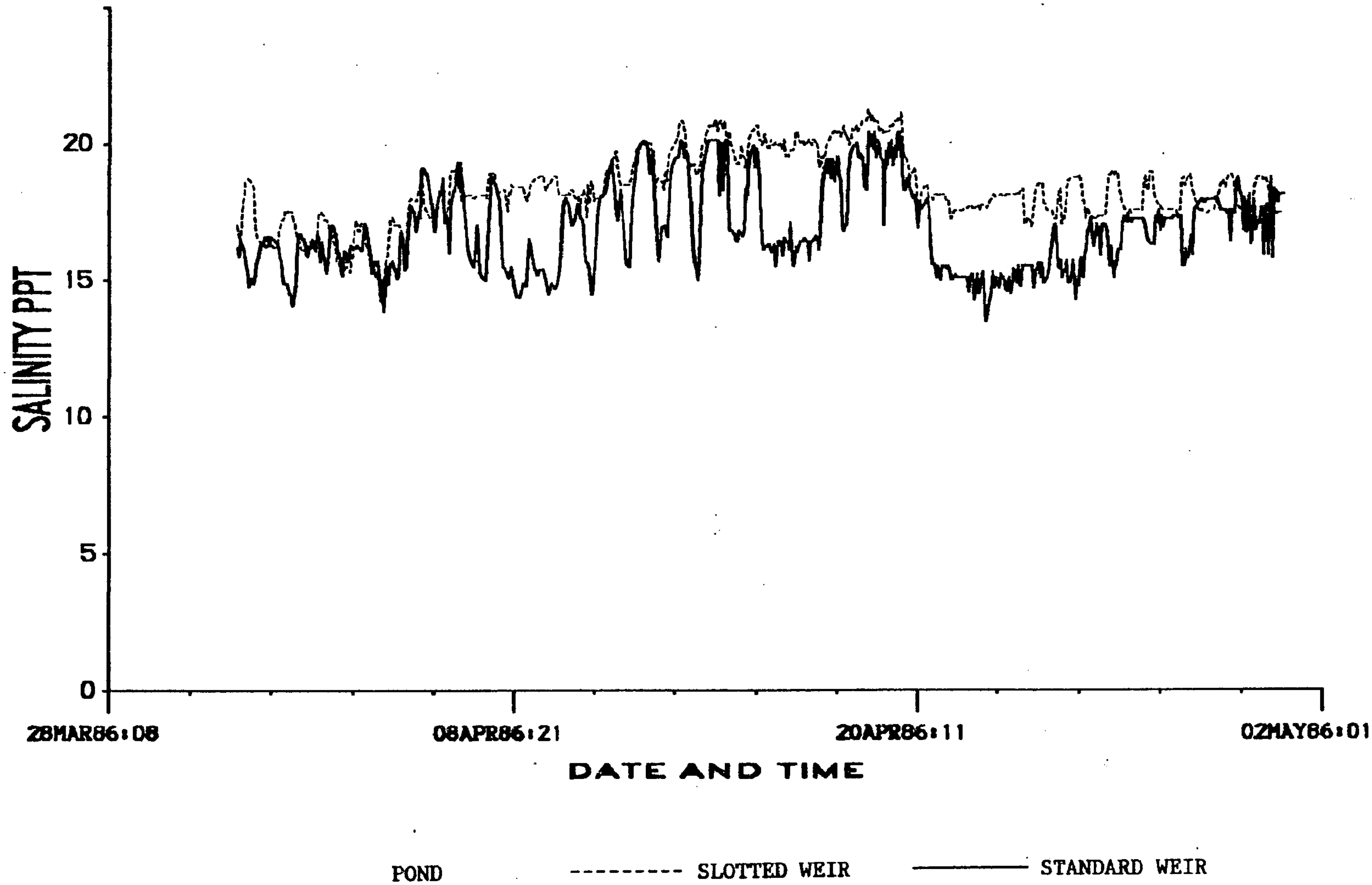
Appendix Figure 30. continued.



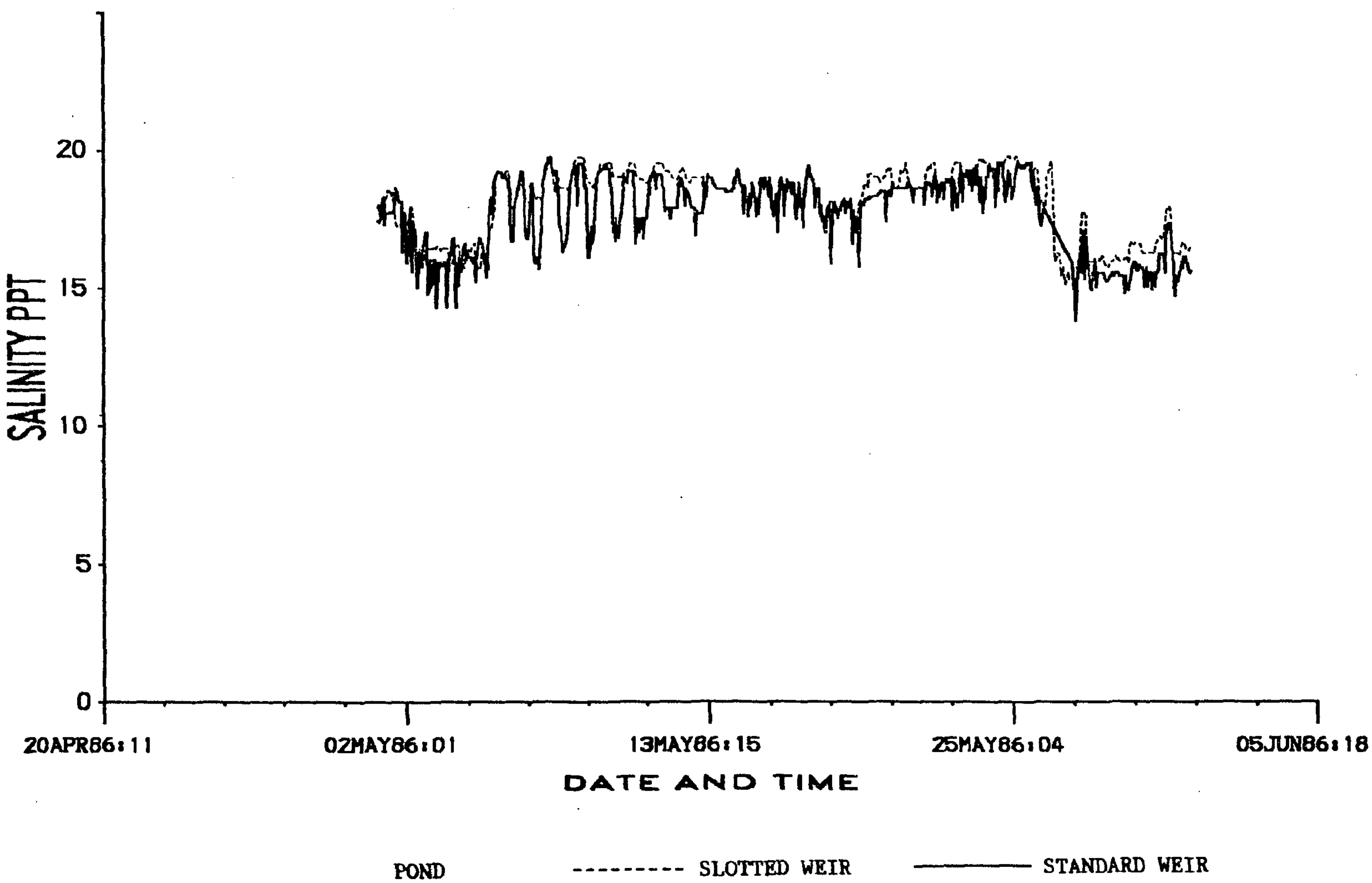
Appendix Figure 30. continued.



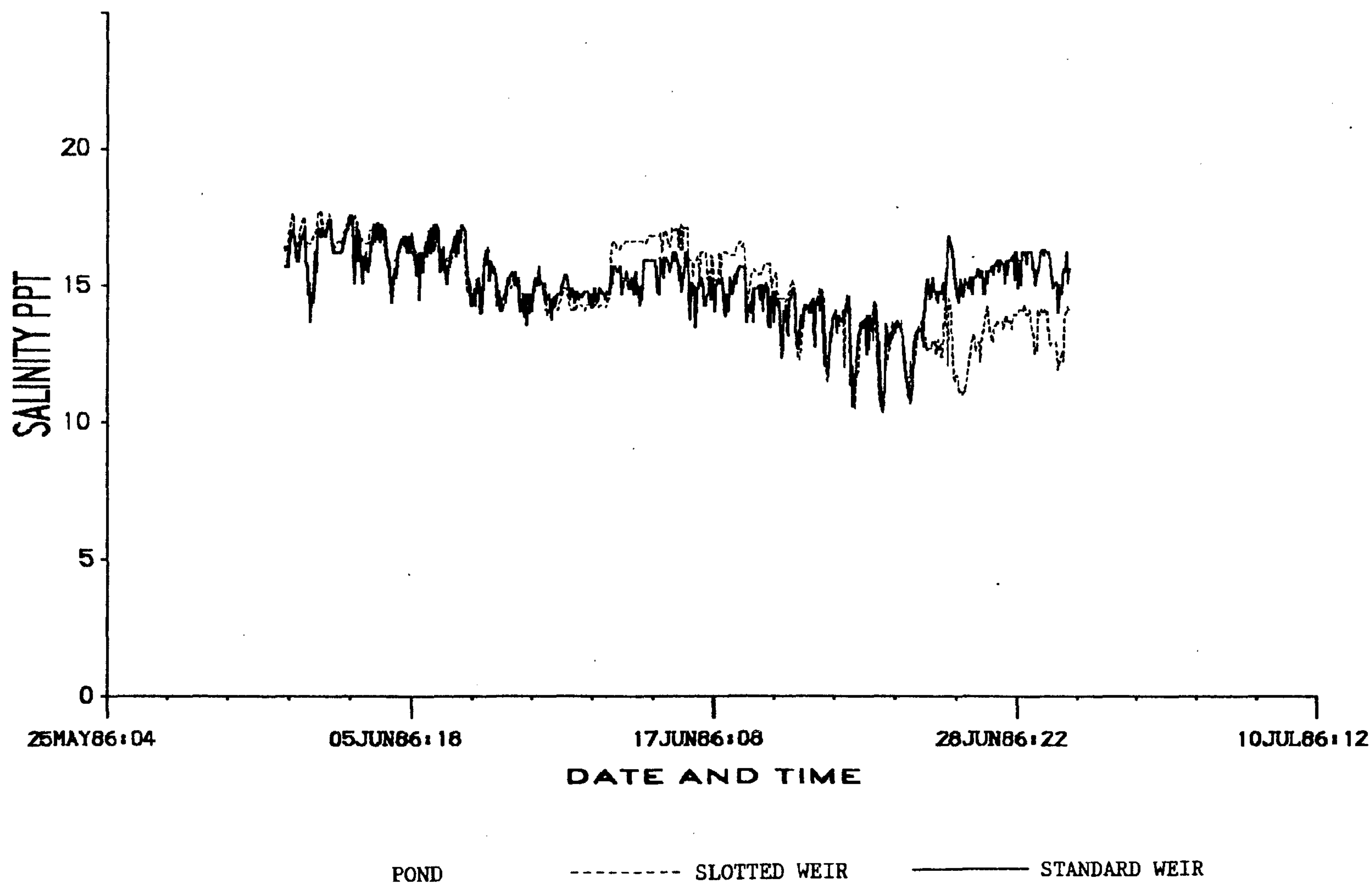
Appendix Figure 30. continued.



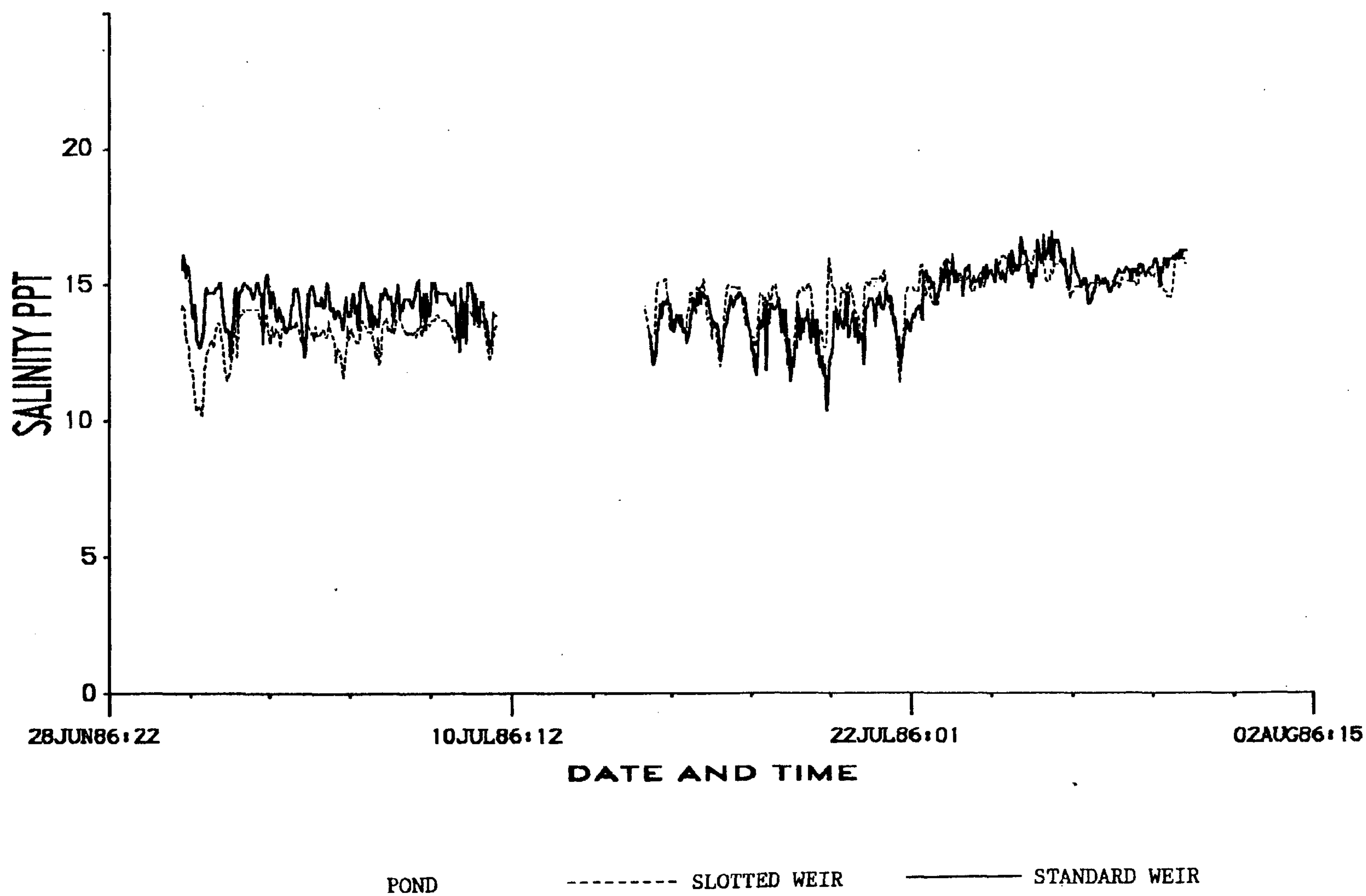
Appendix Figure 30. continued.



Appendix Figure 30. continued.

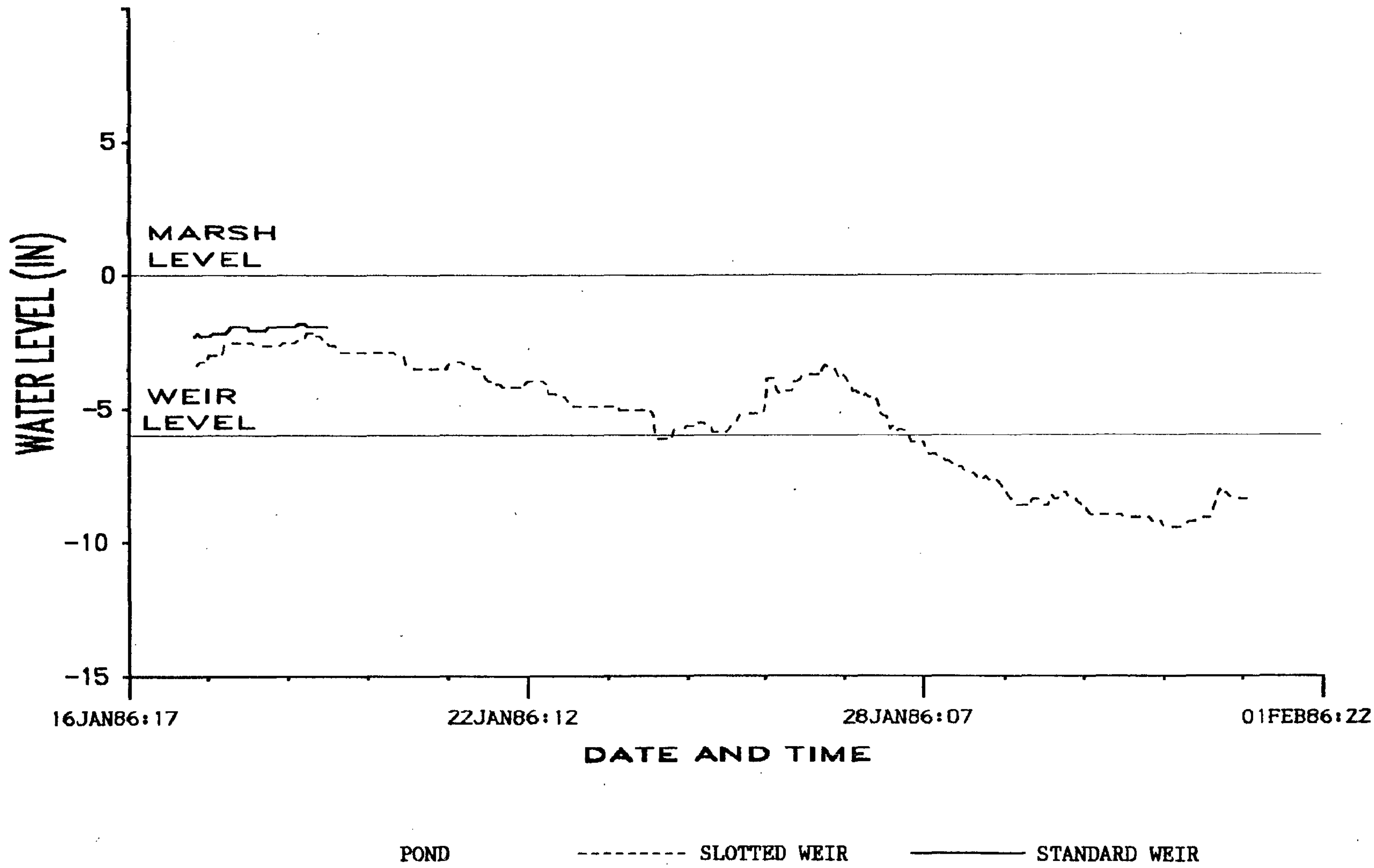


Appendix Figure 30. continued.

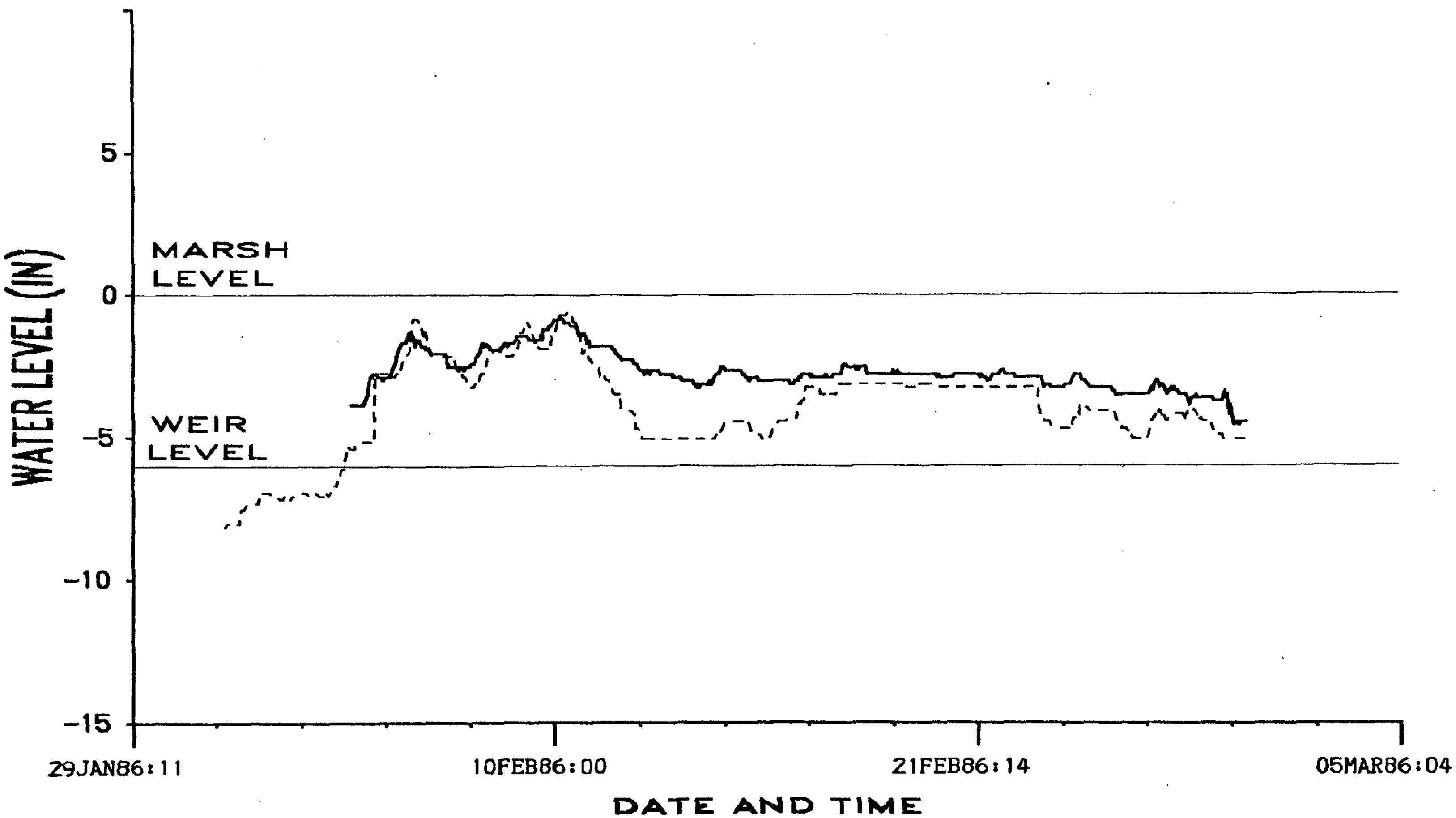


Appendix Figure 30. continued.

Appendix Figure 31. Hourly water levels taken by the Leupold-Stevens tide gauge at the environmental stations in each experimental pond, from 17 January 1986 through 30 July 1985.

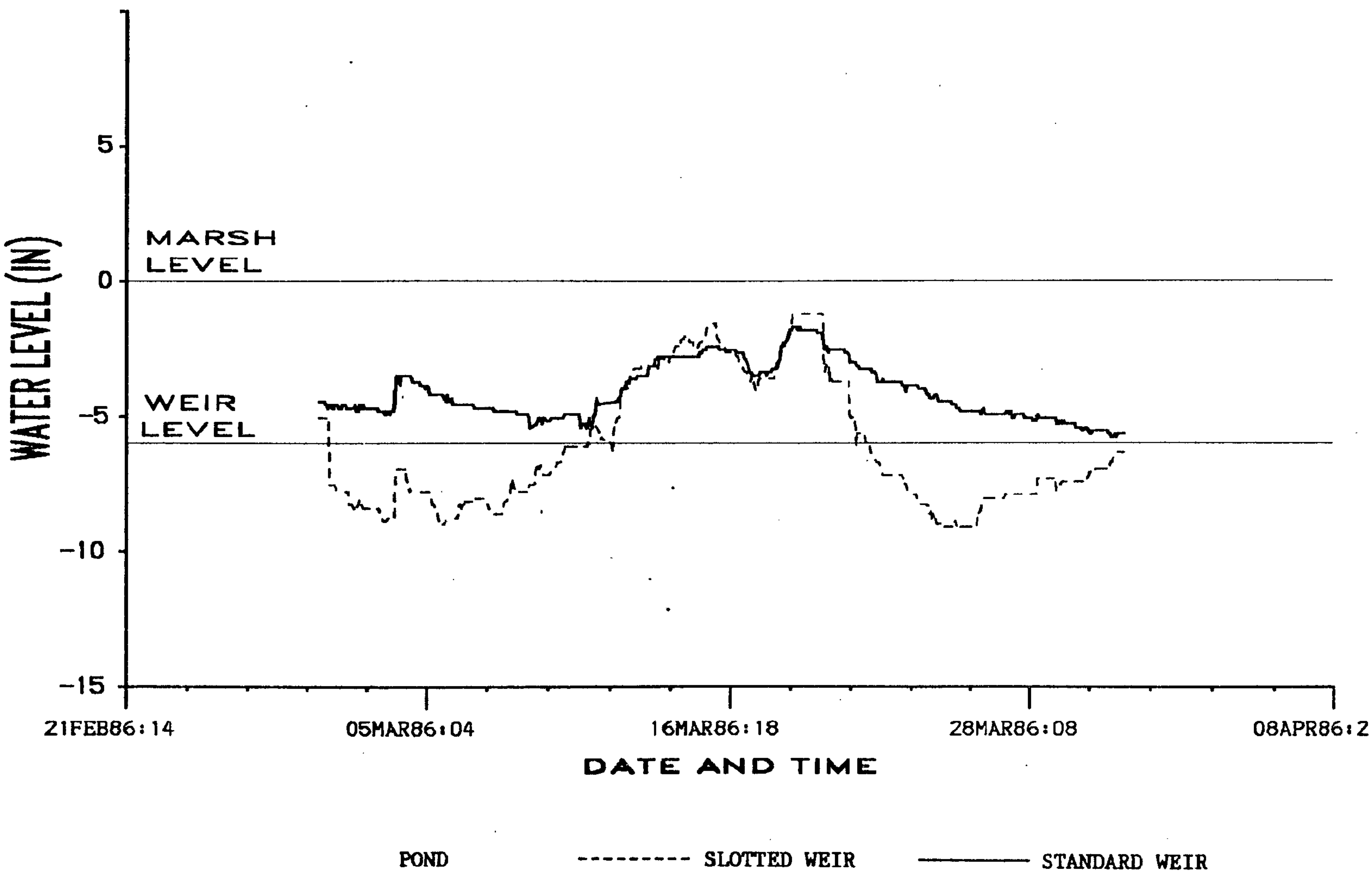


Appendix Figure 31. continued.

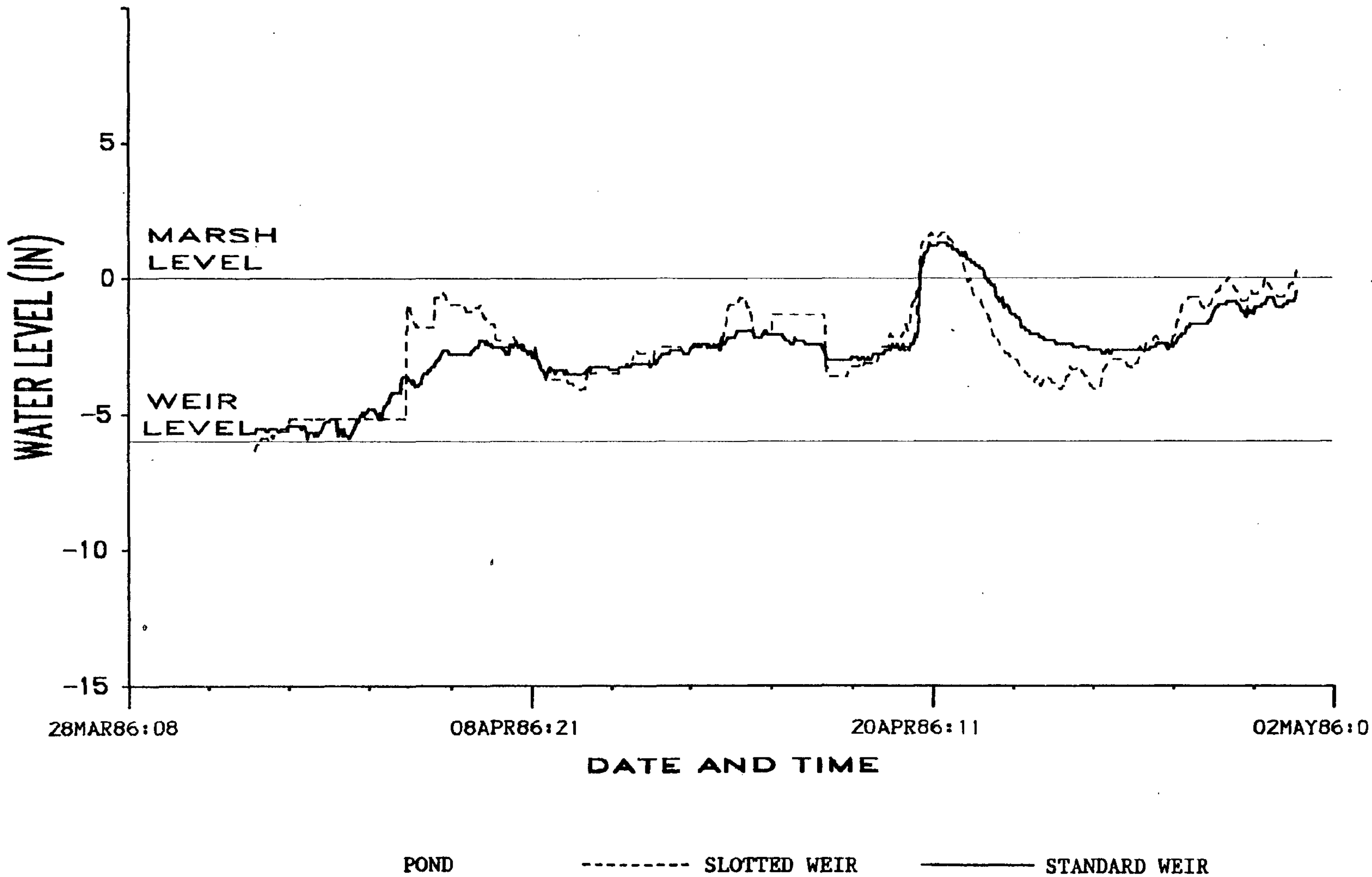


POND --------- SLOTTED WEIR ——— STANDARD WEIR

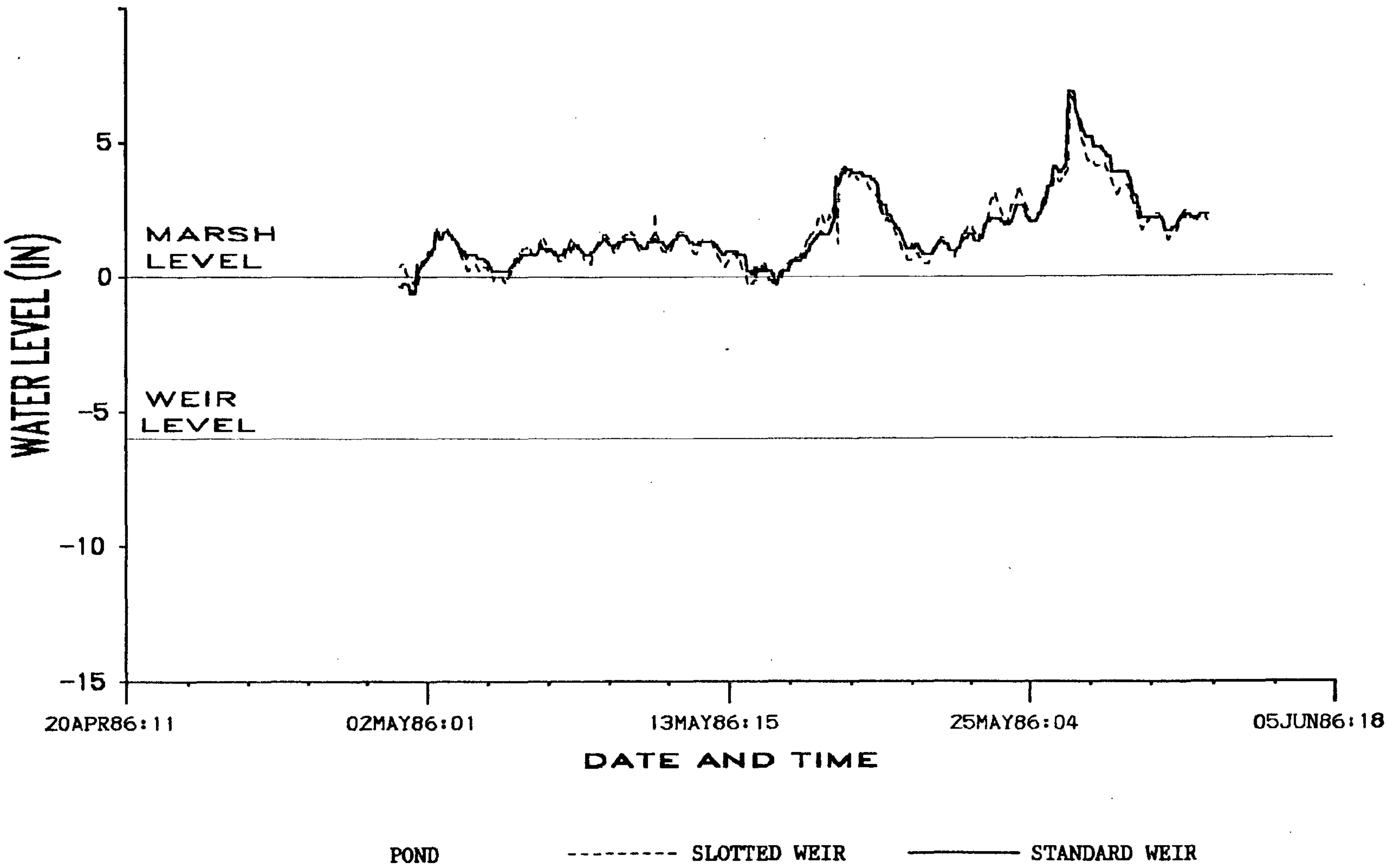
Appendix Figure 31. continued.



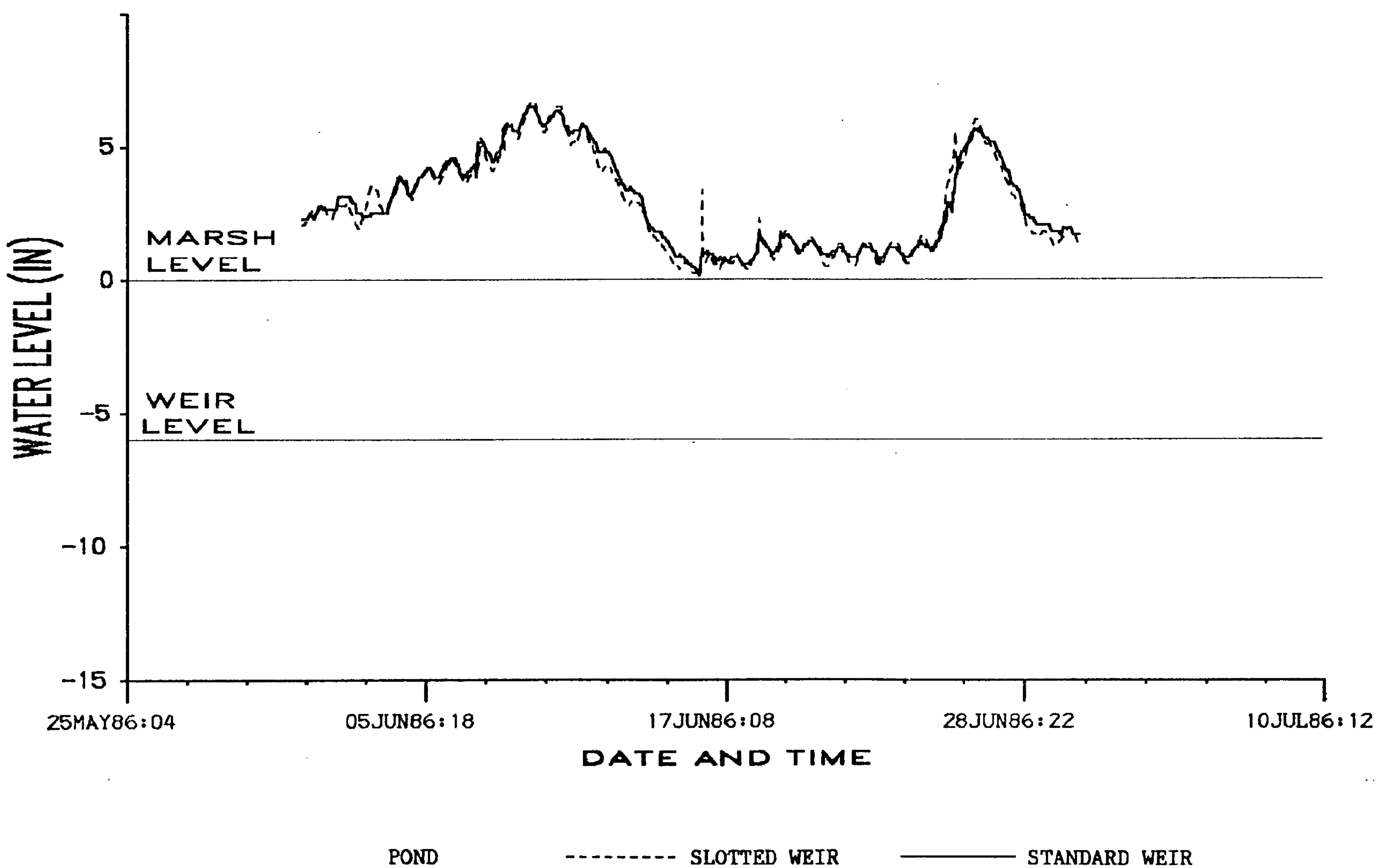
Appendix Figure 31. continued.



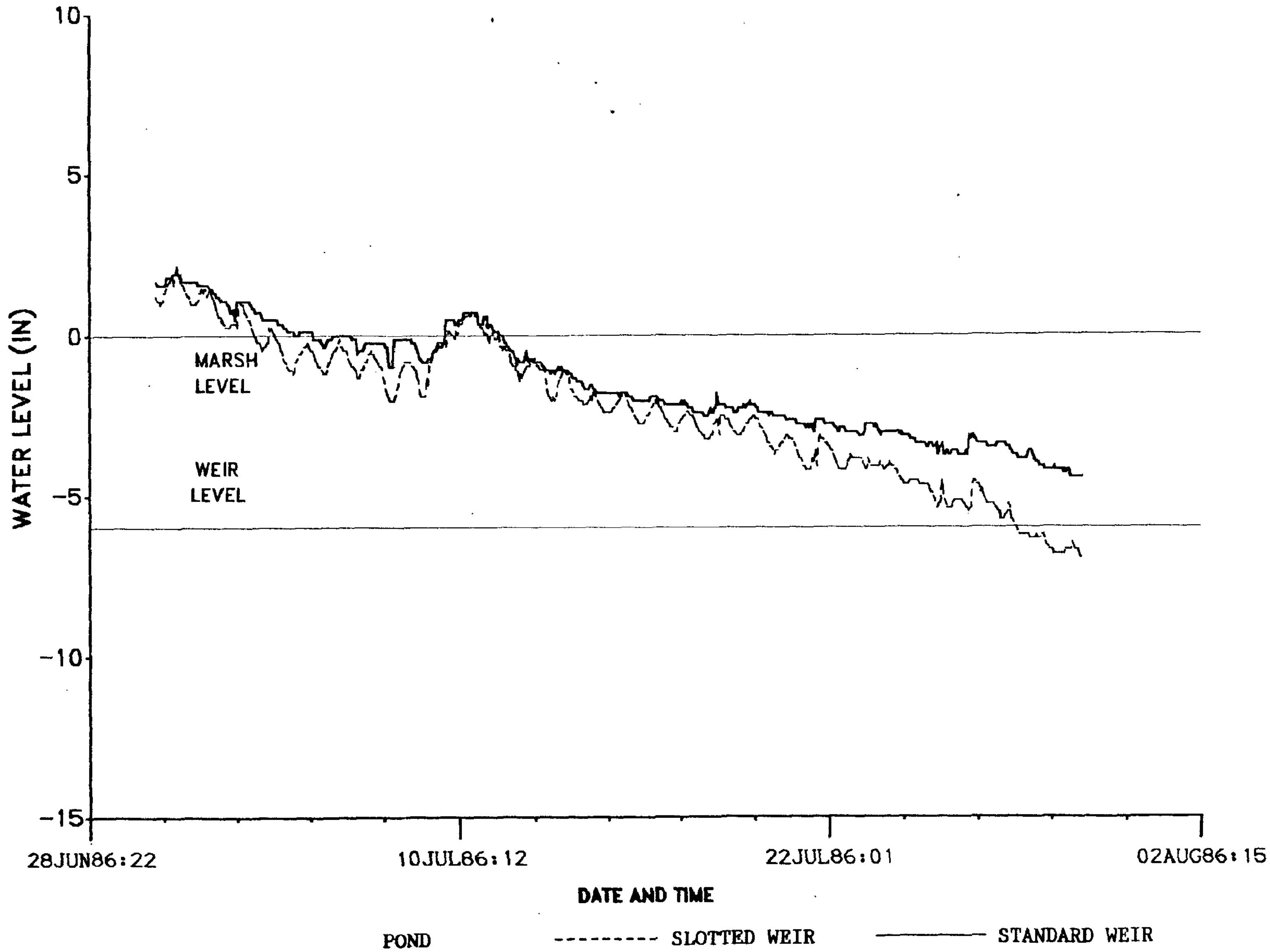
Appendix Figure 31. continued.



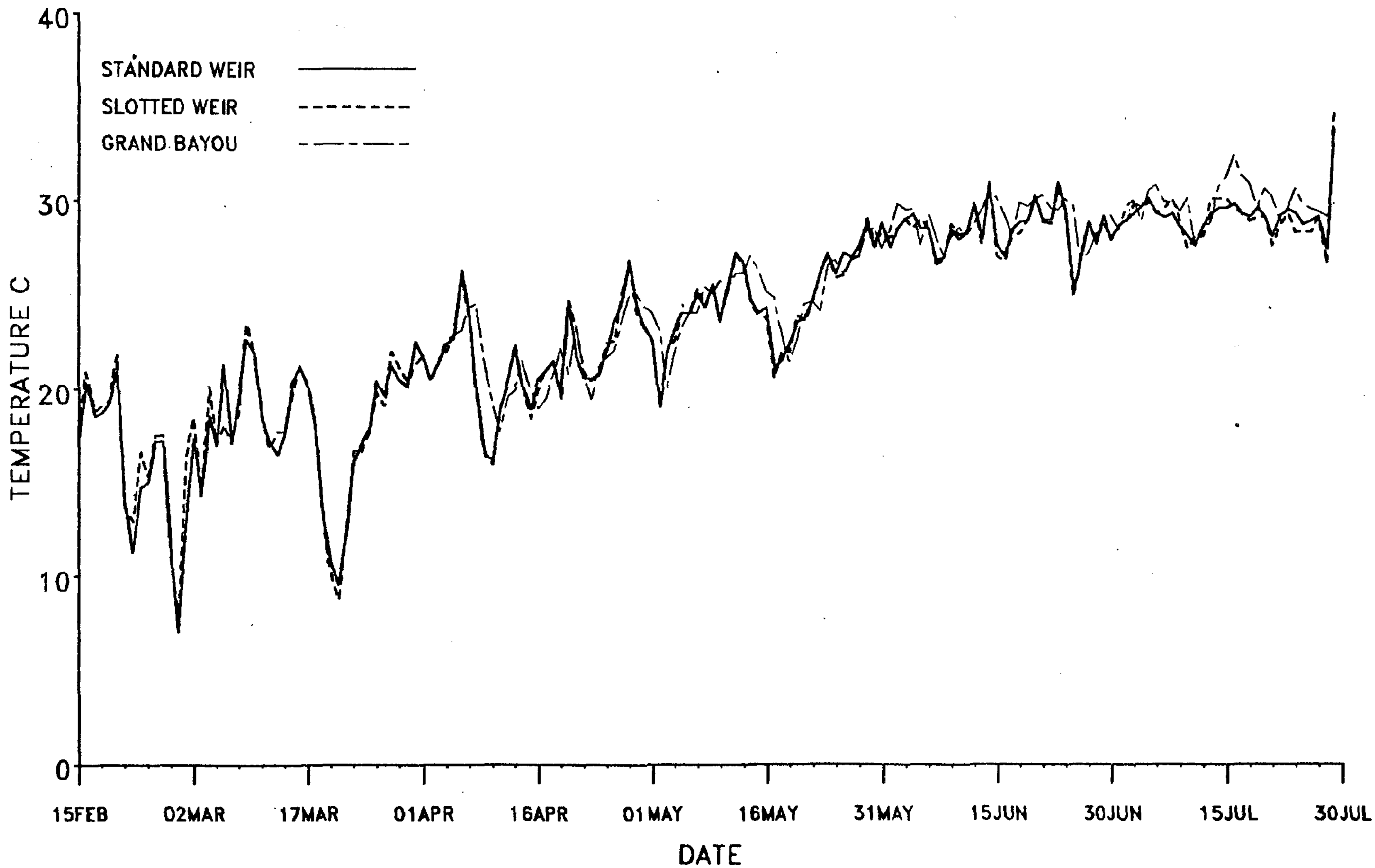
Appendix Figure 31. continued.



Appendix Figure 31. continued.



Appendix Figure 31. continued.



Appendix Figure 32. Daily temperature at the levee stations in the experimental ponds and the average daily temperature at the Grand Bayou stations.